



BEST MANAGEMENT
PRACTICES FOR

Aquaculture

in Wisconsin and the Great Lakes Region

Jeffrey A. Malison and Christopher F. Hartleb, editors

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1.1 Yellow perch phenotypes. The bluish color of the fish on the bottom often results from fish eating formulated versus live feeds. *Brian Sloss, UW-Stevens Point*

1

Overview of aquaculture and the need for best management practices

by Jeffrey Malison

Introduction

The most common definition of aquaculture is the controlled cultivation of aquatic animals and plants. Worldwide, aquaculture has been the fastest growing segment of agriculture for the last decade. The reason for this growth is simple — an imbalance between the supply of and demand for seafood products. It is the growth of aquaculture into a major agricultural participant that is driving the need for aquaculture best management practices (BMPs).

Our definition of a BMP is broader than that used in some other contexts. For this manual, we define a BMP as a management guideline or approach designed to minimize or prevent any adverse environmental impacts, to maximize the health and well-being of the organisms being raised, and to encourage efficient and economical production. The purpose of this manual is to provide guidance for current and prospective aquaculturists in Wisconsin and the Great Lakes region. Statements in this manual labeled  are not intended to be rules or mandates. Rather, they are suggested actions or plans, and the method of implementation is left to the producer. Best practices must be selected based on site characteristics, sizes of fish farms, and the wide range of organisms raised, and they should be revised as new knowledge and technology arise. The BMPs in this manual are grouped according to specific operations or objectives so they may be considered in context.

Aquaculture in the World

Global Seafood Supply

Since the mid-1980s the capture of fish and seafood from wild fisheries has met or exceeded the “maximum sustainable yield” of worldwide fisheries — estimated to be about 100 million metric tons per year. Consequently, the supply of seafood products from the wild is limited and all additional increases in supply will have to be met through aquaculture. (figure 1.3)

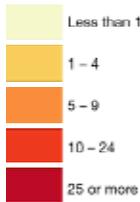
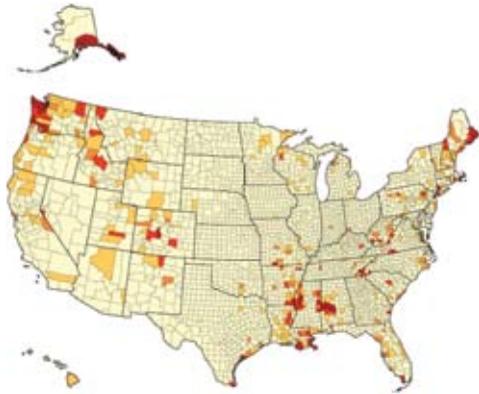
Global Seafood Demand

In 1998, worldwide seafood consumption reached almost 140 million metric tons. And demand for seafood products continues to grow — driven by an increasing world population and the recognition that fish and seafood are an especially healthy source of protein and nutrients.

Aquaculture in the United States

- The United States ranks 12th in the world in commercial aquaculture production. The United States is at a competitive disadvantage with the rest of the world due to high labor costs and a comparative lack of inexpensive coastal properties and resources. The United States may have a competitive advantage, however, in the production of cool- and cold-water species, particularly freshwater species that can be grown on a grain-based diet.
- Currently, the most popular species for U.S. aquaculture are catfish, Atlantic salmon, rainbow trout, crawfish, hybrid striped bass, tilapia, shrimp, and a variety of shellfish. (figure 1.2) Beyond these, a wide range of food fish, game fish, baitfish and ornamental species are currently being raised. Additionally, a significant amount of research is being conducted on developing methods for the commercial production of even more species.
- The most common systems used for aquaculture production in the United States are ponds, flow-through, recirculating, net-pens, and hybrid systems using features of more than one of the other four system types. In this manual we will not discuss net-pen systems because of their limited use in Wisconsin and the Great Lakes region.
- There is an important reason to encourage growth in the United States aquaculture industry — seafood products rank 3rd in dollar value, behind oil and automobiles, among all imported products. Clearly, the growth of the United States aquaculture industry can help reduce our foreign trade deficit.

(figure 1.4)

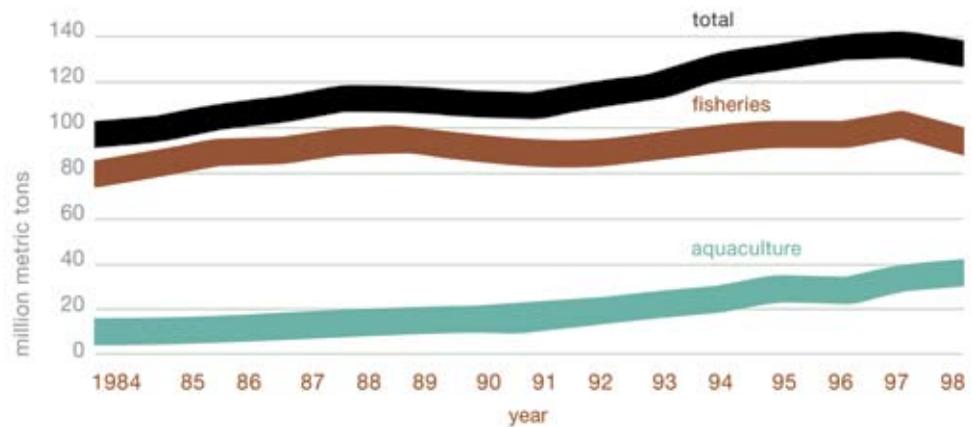


1.2 Value of United States aquaculture sold as percent of total market value of agricultural products sold in 2002 – 0.6%.
U.S. Department of Agriculture, National Agricultural Statistics Service

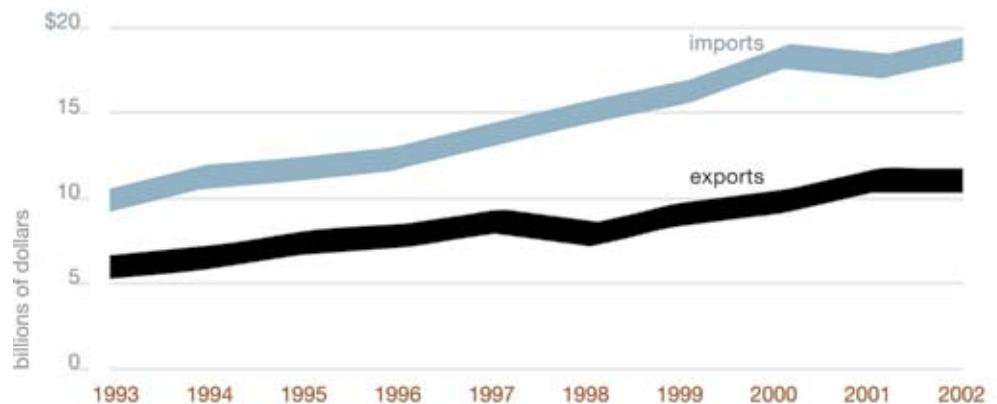
Aquaculture in Wisconsin and the Great Lakes Region

- The aquaculture industry in Wisconsin and the Great Lakes region is not large compared to other areas in the United States, but the industry here is highly diversified, and the region has the water and land resources needed for significant growth.
- The region has both private and public sector hatcheries and fish farms.
- The primary species raised are rainbow trout for stocking and food, various cold-, cool-, and warm-water gamefish fingerlings for stocking, tilapia and hybrid striped bass for food, and several baitfish species. There is great potential for the development of other foodfish species, including yellow perch, bluegill, and walleye.
- The primary system types used in the region are flow-through, open ponds, recirculating aquaculture systems (RASs), and certain types of “hybrid” systems, such as ponds with significant flow-through.

1.3 World fisheries and aquaculture production. *Food and Agriculture Organization of the United Nations (FAO), The State of the World Fisheries and Aquaculture, 2000*



1.4 U.S. foreign trade in fishery products. *USDC/NOAA/NMFS Current Fisheries Statistics No. 2002, September 2003*



- The growth of the industry has been constrained by climate, the lack of technology development for new species, competition from imported products sold at low prices, and outdated regulations that were sometimes developed before aquaculture was a significant industry.

Aquaculture and the Environment

To satisfy the ever-increasing demand for seafood, the development and growth of the aquaculture industry in the Great Lakes region should be encouraged. This growth should proceed with an ethic of sound environmental stewardship and sustainability. To accomplish this we must understand ecological concepts, account for local environmental conditions, and apply scientific methods and reasoning. The goal should be to build a sustainable industry that preserves ecosystem quality and biodiversity for future generations.

Five critical areas of environmental concern need to be addressed:

1. Water use
2. Water/waste discharge
3. Land use
4. Introduction/spread of non-native species
5. Introduction/spread of diseases

Aquaculture Best Management Practices

- Aquaculture BMPs must be site specific because of the great variation in the types of systems used, species raised, and the location and size of farms.
- BMPs can be mandatory or voluntary. Where voluntary, there must be producer incentives to assure implementation.
- A viable method to verify the implementation of BMPs must be developed.
- BMPs can be preferable to the establishment of numerical limits, because
 1. Aquaculture farms in the region are very diverse.
 2. Appropriate numerical limits can be difficult to determine.
 3. Aquaculture is often not characterized by a steady state, but rather by sporadic or episodic events, such as pond filling and draining, fish stocking and harvest, and disease outbreaks.

- The approach of allowing operations to develop BMPs to deal with environmental concerns is similar in concept to the model used for food processing and distribution. To ensure food safety and quality, regulators have implemented a program known as Hazard Analysis and Critical Control Points (HACCP). This system requires food processors to develop specific procedures tailored to their individual system and needs.
- The Environmental Protection Agency (EPA) recently released new national rules regarding the discharge of aquaculture wastes into the environment. The complete rule can be found at <http://www.epa.gov/fedrgstr/EPA-WATER/2004/August/Day-23/w15530.htm>, and a summary of the rule is at <http://64.233.167.104/univ/olemiss?q=cache:vmlElpWh4IgJ:www.olemiss.edu/orgs/SGLC/24>. The rules are applicable to recirculating, net-pen, and flow-through systems that discharge for more than 30 days per year. They do not apply to pond systems that discharge for fewer than 30 days per year. They apply only to operations that produce or hold more than 100,000 lbs. of fish per year. The primary requirement of the rules are that facilities must develop and certify BMPs to minimize the release of potentially harmful substances into the environment. The national EPA rules can be superseded by more stringent regulations and/or numerical limits imposed by states.
- Most regulations regarding aquaculture are developed and enforced at the state level. In this manual we have included a set of guidelines and rules that have been developed for aquaculture in Wisconsin (see Appendix II). As with most states' regulations, they are not perfect. We are including them simply as an example. These have been developed by two Wisconsin regulatory agencies — the Wisconsin Department of Natural Resources and the Wisconsin Department of Agriculture, Trade and Consumer Protection. Hopefully, aquaculture specialists in other Great Lakes states will take the time to insert their state guidelines and rules into the electronic copies of this document that will be distributed across these states.



2.1 Artesian spring showing water flowing from the ground. *Chris Hartleb*

2

Water for aquaculture

by Jeffrey Malison

Water source

There are essentially three types of water available for aquaculture use.

1. Ground or well water is generally free of impurities and biologicals that can affect the aquaculture system. Many locations in the Great Lakes region have abundant groundwater resources, but **care should be taken to site aquaculture systems in areas where the resource will not be depleted by its use.** The temperature of groundwater remains relatively constant throughout the year. Groundwater usually contains little oxygen, and may be supersaturated in nitrogen or total gas concentration. **Aeration can usually be used to alleviate problems related to the gas content of groundwater.** Groundwater may also contain hydrogen sulfide (H_2S), which can be detrimental to fish. **Hydrogen sulfide can be eliminated in water by aeration or the addition of potassium permanganate.** Groundwater may also contain high levels of iron. Unless present at very high levels, iron is usually not harmful to fish, but it can build up and clog water pipes, pumps, wells and other equipment. **If necessary, iron concentration in water can be reduced by using sand filtration.** *(figure 2.1)*



2.2 Water being diverted from a stream into flow-through raceways for trout production. *Chris Hartleb*

2. Surface water consists of water taken from lakes, rivers, or ponds, or it can consist of rain and snow water directly collected for aquaculture use. Surface water usually contains a variety of organisms that can cause problems if introduced into the aquaculture system. These organisms can include phytoplankton, zooplankton, fish, and other aquatic animals. **o m p** Screens, rotating drum filters, or sand filters can be used to reduce or eliminate these problems. Surface water can also contain fish pathogens (viruses, bacteria, and parasites), suspended solids, pollutants, or chemicals (e.g., biocides, fertilizers, or animal waste products), which can be problematic. The temperature of most surface water varies seasonally. Also, in many locations the water level or flow rate of surface waters may vary seasonally or from year to year (e.g., in excessively wet or drought years). **o m p** Care should be taken to site aquaculture systems in locations where adequate water is reliably available throughout the year. *(figure 2.2)*
3. Municipal water can be used for recirculating aquaculture systems (RASs) that do not require a high volume of water. Municipal water can be costly to use, and care must be taken to remove chlorine and chloramines. **o m p** Chlorine removal can be done by using activated charcoal filters, or by metering sodium thiosulfate into the incoming water stream.

Water volume needed

The requirement for water varies greatly depending on the type of system used. Flow-through systems require a high volume and constant flow of water. Ponds are intermediate in their need for water. They generally require a high volume for filling, but then only a small volume to make up for leakage and evaporation. RASs require less water than the other two system types. A general rule of thumb is that for every pound of fish produced, 5-50 gallons of water is needed for RASs, 200-800 gallons for pond systems, and 10,000-35,000 gallons for flow-through systems.

The costs of pumping water can be significant. In some locations, systems can be designed in which the water flows by gravity into and through the aquaculture system, thereby avoiding pumping costs. These systems generally rely on the use of artesian wells or surface water.

Regulations on water use

- A. Groundwater — In most locations, a permit is needed for high-capacity wells (e.g., > 70 gallons per minute).
- B. Surface water — Regulations on the use of surface water varies from state to state. Regulations on water use in Wisconsin can be found in Appendix II.

Water quality within the system

Temperature

Water temperature is the primary factor that determines which fish species can be raised in a particular facility. All fish species have a range of temperatures over which they can survive and grow well, but fish also have a thermal maximum, which is only slightly above their optimum for growth. If the temperature exceeds this thermal maximum for only a brief period of time, the fish become stressed and disease outbreaks are likely. At worst, catastrophic mortalities can ensue. Some warm-water fish also have a thermal minimum, below which they become stressed and/or die. For example, the cool-water yellow perch will survive temperatures between 33 and 80°F. In temperatures below 50°F they grow slowly or not at all. They grow well in temperatures between 65 and 78°F but become stressed in temperatures higher than 80°F.

h m p When designing and siting an aquaculture facility, never allow the water temperature to exceed the maximum for the species for prolonged periods of time. At the same time, however, it is important to have water temperatures at or near the optimum for growth for as many days during the year as possible.

One of the advantages of RASs is that they can usually be designed to provide for constant water temperatures throughout the year, thereby extending the growing season. Similarly, flow-through systems using groundwater can allow for year-round growth. Groundwater temperatures in the Great Lakes region range from about 45°F in the northern part of the region to 65°F in the south. For pond culture, a rule of thumb is that water temperatures permitting good growth should be available for at least 6 months of the year. Based on this rule, most ponds in the Great Lakes region seem best suited for the culture of cool-water fish species.

h m p It should go without saying that water temperature should be regularly measured in systems subject to regular changes in temperature. (figure 2.3)

2.3 A DO meter checks temperature and dissolved oxygen. James A. Held



Dissolved oxygen

Oxygen is the first factor that limits production in any aquaculture system. In other words, as fish density and food requirements increase, oxygen is consumed and becomes the first rate-limiting factor. Cold water can contain more oxygen than warm water, but cold-water fish generally require higher concentrations of oxygen than warm-water fish. Each fish species has a range of oxygen concentration at which they can function normally. Below this range, physiological functions are adversely affected, and stress, disease and death can occur.



2.4 Packed column aerator.
Chris Hartleb

o m p For any system type, oxygenating incoming water can usually be done at little or no cost by running water through a packed column. In flow-through systems and RASs, significant, cost-effective increases in production can usually be made by using supplemental mechanical aeration (electric or wind powered) or liquid oxygen injection. Supplemental aeration is also being used increasingly with pond systems as they become more intensive.

In flow-through systems, incoming aerated water and supplemental aeration are the primary sources of oxygen. In RASs, supplemental aeration is the primary source of oxygen. In pond systems, the primary sources of oxygen are gas exchange at the water's surface, and photosynthesis of plants during the daytime hours.

o m p The regular measurement of oxygen is one of the most important management practices in aquaculture. Low oxygen levels are probably the cause of more catastrophic fish losses than all other causes combined. Oxygen levels vary significantly in most aquaculture systems. They normally decline about 30-60 minutes after fish are fed and also can decline quickly when fish are handled or otherwise stressed. In ponds, oxygen concentrations usually undergo a significant daily rhythm, declining to their lowest level at dawn. Because of this rhythm, the use of emergency or supplemental aeration is focused during the nighttime and early morning hours. (figure 2.4)

pH

The pH of water has both direct and indirect effects on fish. For most freshwater fish species the desired pH is between 6 and 9, and water that is either too acidic or alkaline can directly harm fish. Indirectly, pH affects nutrient availability and the toxicity of some substances, the most important of which is ammonia (see below). **o m p** Accordingly, the regular measurement of pH is another important management practice in aquaculture.

The pH of water that is weakly buffered is subject to drastic changes, whereas the pH of well-buffered water changes more slowly. The pH of water in RASs generally tends to decline over time because of the accumulation of dissolved chemicals. Different forms of calcium carbonate, such as lime or crushed oyster shells, can be used to increase buffer strength in recirculation systems and



2.5 Using a HACH kit to measure ammonia or nitrite.
Chris Hartleb

ponds. It is generally not practical to increase the buffer strength of water in flow-through systems.

Ammonia

Ammonia is the primary nitrogenous waste product of fish. It is soluble in water and dissociates into ionized and unionized chemical states. Unionized ammonia is highly toxic to fish, and **because of its toxicity the regular measurement of ammonia is an important management practice in many aquaculture systems.** The build-up of ammonia is the second factor that limits production in any aquaculture system. In other words, as fish density and food requirements increase, ammonia is produced and becomes the second rate-limiting factor, assuming that adequate oxygen levels are maintained. The ratio of unionized/ionized ammonia increases dramatically with increasing pH and temperature. For example, at 68°F, less than 1% of the total ammonia is in the unionized form at a pH of 7.4, but more than 20% is unionized at a pH of 8.8. At a pH of 8.0, less than 2% of the total ammonia is in the unionized form at 52°F, but more than 7% is unionized at 85°F.

In flow-through systems, ammonia is removed from the system by flushing with the constant addition of fresh water. In RASs, ammonia is usually removed from the system by nitrification in a biofilter, which converts *ammonia* ⇌ *nitrite* ⇌ *nitrate* (see Chapter 8). The direct absorption of ammonia by clinoptilolite filters is also possible. In pond systems, ammonia is nitrified to nitrite and nitrate by natural bacteria living in the pond and pond substrate. (*figure 2.5*)

Nitrite

As mentioned above, nitrite is an intermediate product of the nitrification of ammonia. Like ammonia, nitrite is highly toxic to fish. Since little nitrification normally occurs in flow-through systems, the measurement of nitrite is not normally required. **In RASs and pond systems, however, the measurement of nitrite is usually an important management practice.** Excess levels of nitrite interfere with the normal transport of oxygen by hemoglobin in the blood, resulting in so-called “brown blood” disease. The negative effects of nitrite on oxygen transport can be partially ameliorated by the addition of a small amount of sodium chloride (NaCl, common salt) into the rearing system. This is a common practice in RASs, and it is also used in some pond systems.

Nitrate

Nitrate is the usual end product of nitrification. Fortunately, nitrate is harmful to fish only in very high concentrations. In ponds and flow-through systems, nitrate does not usually build up to levels that cause concern. Nitrate can reach significant concentrations in RASs. Here, excessive nitrate levels are controlled by flushing and by denitrification — the conversion of nitrate to nitrogen gas by bacteria.



2.6 Secchi disc. *Geo Scientific Incorporated*

Solids

In flow-through systems and in ponds, solids should normally not build up within the system to levels that can harm fish. In flow-through systems, the bulk of solids consist of uneaten food particles and large fecal particles that settle to the bottom of the rearing unit. These are often swept by current towards the back of the rearing unit. From here, they can be pumped out of the unit (side-stream discharge) or manually swept out with the normal current flow.

In ponds, most waste solids remain in the pond and are biologically consumed by organisms on the pond bottom. Most of the suspended solid material in a pond consists of living organisms — phytoplankton and zooplankton.

omp A common pond management strategy is to use a Secchi disk to measure the turbidity of the pond. (*figure 2.6*)

The Secchi measurement is usually well correlated to the fertility/primary productivity of the pond. In large ponds, wave action created by strong winds can stir up clay and other bottom sediments. Extreme levels of suspended sediment can reduce primary productivity of the pond, or even clog or irritate fish gills.

omp For this reason, in areas subject to frequent high winds, ponds with earthen levees exposed directly to the water can be designed with their long axis perpendicular to the most common wind direction. Alternatively, shorelines exposed to heavy winds can be riprapped to reduce the suspension of sediments.

In RASs, the removal of solids is one of the key elements of system design and function. The removal of solids from the system often breaks particles into smaller sizes, which become difficult to remove from the system and can cause injury to gills of the fish. The removal of solids from RASs is discussed further in Chapter 8.

Carbon dioxide

At high concentrations carbon dioxide (CO_2) can reduce pH to stressful levels and interferes with gas transport through the gills. Carbon dioxide concentrations are not problematic for flow-through and pond systems, but must be a consideration in the design and management of high intensity RASs. Carbon dioxide accumulates in these systems because of the high level of respiratory activity by the fish and bacteria in the biofilter. **omp** Carbon dioxide is usually stripped from water through the use of packed columns or other types of mechanical aeration. Accordingly, high carbon dioxide levels have become more problematic as liquid oxygen systems have gained popularity and have replaced conventional mechanical oxygenation systems.

Nitrogen

The primary problem caused by nitrogen in aquaculture systems occurs when nitrogen becomes supersaturated in the water. Frequently, groundwater or water that is pressurized by pumping can become supersaturated with nitrogen. Supersaturated water causes gas bubble disease in fish, a problem similar to the bends in divers. Problems with nitrogen supersaturation are normally not associated

with ponds, but they can occur in flow-through and water recirculation systems. If problems are suspected, **omp** a common management strategy is to measure the concentration of nitrogen in the water with a gas saturometer. To reduce nitrogen levels, the water must be mechanically aerated or run through a packed column. Sometimes, nitrogen supersaturation is caused by an air leak in the water supply tube to a pump, which allows air to be aspirated into the pump and mixed under pressure with water. In this case, simply plugging the air leak can solve the problem. *(figure 2.7)*

2.7 Using a saturometer.
James A. Held



3

Management and beneficial reuse of aquaculture wastes & effluents

by Steven Yeo

Overview

To sustain a commercially viable level of production in intensive and semi-intensive aquaculture facilities, feeding of formulated diets or the boosting of food production through fertilization is necessary. The principal source of aquaculture waste is ultimately from the food that is fed to the fish, which enters the waste stream either uneaten or as excreted waste. Fertilization to boost natural food production processes in the aquatic systems can also result in excess nutrient levels. Phosphorus (P) and nitrogen (N) of dietary origin are of principal concern as potential contributors to the eutrophication of aquatic systems. Organic waste solids from uneaten food and fish excrement are a source of stimulation for microbial decomposition. When in excessive abundance, these wastes can degrade the available oxygen supply and tax the natural decomposition capabilities of aquatic systems. This oxygen-degrading potential of organic waste is termed the biochemical oxygen demand (BOD). To prevent mortalities and to manage the overall rearing environment, a limited number of therapeutants (sometimes added to the feed), fertilizers, and other chemicals are occasionally necessary. These wastes result from the aquaculture rearing process and aren't necessarily derived directly from the food.

Because of differences in the amount of water used and method chosen for flushing wastes from the system, the degrading strength of wastes produced by different types of production systems can vary considerably. [See Yeo, Binkowski, and Morris (2004) for more extensive discussion of characteristics of waste and system comparisons.]

Wisconsin's regulations on the discharge of water to surface bodies of water are presented in Appendix II part C.

Managing Waste Output from the Uneaten Portion of Food

Some general recommendations apply to fish feeding regardless of the type of rearing system used. Most uneaten food is a result of factors related to feed management and can be controlled through diligent observation and management by the farmer. Aquaculture feeds contain principally protein, carbohydrates, lipids, and relatively minor amounts of antioxidants, vitamins, pigments, and a limited number of regulated therapeutic agents. Uneaten food is an excellent growth medium for oxygen-consuming microbes that generate a high BOD. It can be more polluting than the metabolic wastes from the unused portion of the food actually consumed and excreted by the fish.

Feeding Recommendations

 Never overfeed your fish. Efficient feeding is required both for cost-effective production and to minimize unused feed.

 Feed your fish taking into account the temperature, rearing system, species differences, and life-stage differences.

- Since fish are cold-blooded, their feeding activity and metabolic needs vary with the rearing temperature. Less food is required at colder temperatures.
- In outdoor systems, feeding of formulated diet is commonly halted, or at least reduced significantly, during the winter, even when growing cold-water fish like salmonids.
- Conversely, more food is required at higher temperatures. However, less dissolved oxygen is present at higher temperatures, so oxygen demand from wasted feed and the higher metabolism of the fish can more rapidly degrade the rearing environment.
- Feed management should complement the species and the rearing system. Demand or mechanical feeders may be appropriate for some species, and hand feeding may be appropriate in other cases. Observation of fish behavior

during hand feeding is a very useful adjunct to manufacturer feeding guides. Floating feeds may be appropriate in situations like ponds, and sinking feeds may be effective in systems like flow-through raceways.

- Fish metabolic needs also vary with life stage—generally, small-sized juvenile fish need more frequent feeding (e.g., 6-8 feedings per day) and a higher ration in relation to their body size than older, larger fish that might be fed only one or twice a day.

For waste feed reduction, Westers (1995) offered the following seven recommendations:

omp The potential of the diet must be known for the size and species of fish. This may require food labeling, including information on digestibility and waste generation, such as quantity of solids, nitrogen and phosphorus. Also, labeling should provide information on feed conversion and growth rate obtained under controlled conditions.

omp The weight of all fish in the system must be known.

omp The health and condition of the fish must be known (appetite).

omp Fish should be relatively uniform in size and capable of accepting a single-sized pellet.

omp Broken pellets and dust should be sifted out before feeding, and feed systems must not damage the pellets.

3.1 Different sizes of fish food. *James A. Held*



omp Feed should be applied by the method that maximizes its consumption by fish.

omp Feed should be applied at slightly below maximum ration.

- Some small amount of uneaten food seems to be inevitable and difficult to quantify.
- The particle size, surface area to volume ratio, moisture content, density, and presence of binding agents influence the settling properties and durability of uneaten food in water.

omp Feed small fish frequently — as often as 6-8 times daily. Most larger fish (> 4”) do not need to be fed more than once or twice daily.

omp Observe fish feeding behavior in situations where fish are visible. Keep records of feed used and sample growth periodically to determine food conversion efficiency, especially in situations where visual observation is difficult.

Managing Waste Output from the Eaten Portion of Food

The difference between the content of an element in the food and what is retained in the fish can be used to estimate the waste output of aquaculture activities. Both the particulate and dissolved excretory wastes are derived from the portion of food that is consumed but not used by the fish. Any escaped fish, mortalities, and fish-processing waste at harvest are also ultimately derived from the utilized portion of the feed.

Particulate Wastes

- The undigested portion of food, together with mucus, sloughed intestinal cells, and bacteria, is voided as feces with high oxygen-degrading potential and toxic metabolites.
- Particulate wastes include the portion of N or P from the feed that are not digested by the fish. As particulate wastes break down, these nutrients can leach out as dissolved forms. (figure 3.2)

Dissolved Wastes

- Some metabolic outputs are excreted directly in dissolved form and are not readily removable by mechanical means.
- Important metabolic outputs of this type are derived ultimately from the food that is digested but not utilized and subsequently excreted across the gills, or voided in the urine.



3.2 Solids build-up in a raceway. *James A. Held*

- Dissolved nutrients can stimulate plant growth if they are present in sufficient concentration. Depending on the situation, these nutrients can have either the negative effect of contributing to eutrophication of aquatic systems or the beneficial effect of boosting the biotic productivity of infertile systems.

Waste Control and Management Through Feed Formulation

Organic matter, nitrogen and phosphorus wastes derived from feeds can be reduced by the selection of highly digestible feedstuffs and the careful balancing of energy and nutrients, particularly N and P that affect eutrophication.

Phosphorus

Phosphorus reduction is especially important in flow-through and net-pen situations where the volume of water is too great to allow for efficient dissolved phosphorus removal.

- The content, solubility, and availability to fish of phosphorus in formulated fish diets varies with the types of ingredients used.
- The issue of fish meal use in fish diets has been criticized both from a phosphorus and from a world ecological perspective (i.e., diminishing stocks of fish used for fish meal). Fish meal is also one of the most expensive components of fish diets. For these reasons, significant efforts have been made to reduce the fish meal content of many fish diets.

 **Thus, we recommend that aquaculturists be aware of the fish meal content of the food they use, and all of the related ramifications.**

- A certain level of fish meal or other animal protein that contributes some digestible P appears to be necessary for salmonids and carnivorous fish with limited digestive capacity for complex carbohydrates and perhaps for poor-quality proteins. The phosphorus content of fish meal is largely associated with the bone content, which is difficult and costly to separate from the meal.
- The tendency to overuse fish meal rather than including both animal and plant protein ingredients has contributed to excessive N and P excretion, particularly in dissolved form.
- Phosphorus absorbed from the diet in excess of growth needs is excreted in the urine in dissolved form that is more costly and difficult to remove once it has entered an effluent, except perhaps through plant absorption.

 **In outdoor systems, certain plants can be used to remove large amounts of dissolved nutrients and provide the farmer with a valuable by-crop.**

- The nonabsorbed phosphorus that is excreted by fish is in solid form as feces or uneaten food.

o m p Rapid and efficient solid waste removal can reduce the particulate portion of phosphorus discharged before it has the chance to leach out of the solid to a dissolved form.

3.3 Pump cleaning a raceway.
Chris Hartleb



Impressive reductions in the amount of phosphorus excreted by fish have been achieved since the 1990s by reducing the level of total phosphorus in the diet and by formulating the diet so that the amount of phosphorus closely matches the metabolic requirements of the fish. In 1990, rainbow trout diets typically contained ~2% total phosphorus, of which about 65% was available (~1.4% available phosphorus). Current trout feeds are formulated to contain 1.1-1.2% total phosphorus, of which 0.7-0.9% is available. Consequently, urinary losses have been reduced by 70% and fecal losses by 50%. Further reduction of phosphorus excretion may be achieved by increasing the availability of dietary phosphorus, and simultaneously reducing the total phosphorus in diets. The trend toward higher use of plant protein sources in fish diets to replace fish meal will increase the level of not readily digestible phytate in diets. For mostly plant ingredient diets the use of the enzyme phytase is necessary to make plant protein more digestible because of the instability of the enzyme during feed processing and the possibility of solubilizing more P in the solid wastes produced. Another possibility is the use of low-phytate grains.

Nitrogen

Nitrogen reduction through dietary formulation is more problematic for aquaculture diets than reducing phosphorus because fish, like all animals, have an upper limit on the amount of dietary protein that is incorporated into tissue. During the 1990s, large improvements in protein retention of rainbow trout were made by altering diet formulations; similar formulas must be developed for other fish species.

Organic Matter

Organic material reduction through diet formulation involves increasing the digestibility of feed ingredients, especially those of plant-derived ingredients.  Use efficient diet formulations that are designed to efficiently deliver required nutrients to the species reared and minimize waste products.

Beneficial Use of Fish Manure and Aquaculture Sludge

In general, when it is possible to collect and remove solid wastes from the rearing system, the potential benefits and difficulties of using fish manure appear to be similar to those encountered with the use of other animal manures. With regard to fertilizing properties, manure provides a gradual release of nutrients. The nitrogen levels (2-5% dry matter) are not as high and the nitrogen is not instantly available to the plants, as it is with inorganic soluble nutrients. Also, by itself, fish waste may not contain the proper balance of nutrients for plant growth, and the further addition of nutrients may be required to sustain profitable growth. The organic content may act as a soil conditioner in certain cases, improving moisture content.

Land Application

 Land application has become a widely adopted and convenient technique to recycle the nutrients from hatchery pond sludge. Properly applied, this technique safely recycles waste solids while providing limited crop fertilization and improving or maintaining soil structure.

- The nutrient characteristics and fertilizer value of fish manure vary depending on the source materials, the methods of collection and storage, and the method of land application.
- Solids samples showed substantial variation between farms and between types of manure management on the same farm. Age of storage of trout manure influenced the quality. With regard to heavy metal content, zinc levels have been found to be slightly high, but not high enough to be limiting to land application.

 To avoid environmental damage, land application of aquaculture waste slurry should take into account site conditions, timing of application, application rates, crop type, crop uptake capacity, crop rotation, and land availability for application. The Idaho Division of Environmental Quality (1997) has published guidelines for removal and land application of aquaculture waste that are appropriate for large-scale salmonid hatcheries.

However, the amount of wastes generated from even a large aquaculture facility has the potential to benefit only a relatively small amount of cropland when properly applied. One hundred acres of land is adequate to accommodate biosolids produced by a properly operated aquaculture facility with a swimming inventory of one million pounds, feeding 15,000 pounds of feed per day (IDEQ 1997).

Typically, smaller operations in the Great Lakes region generally produce less than one million pounds annually, and the potential nutrient benefit of aquaculture waste to cropland is generally too small to provide incentive for its incorporation into field crop management planning. Smaller-scale horticultural alternatives may be more appropriate beneficial uses.

For smaller-scale agricultural, landscape, or gardening application, further processing and stabilization of raw waste by composting is probably justifiable for handling, storage, and marketing reasons.

Regulations on the land application of aquaculture waste in Wisconsin can be found in Appendix II part B.

Constraints on the land application of aquaculture sludge

- Surface land application of aquaculture sludge can produce an undesirable odor.
- Excessive application beyond the level the plants utilize can potentially lead to excess nitrates leaching into groundwater supplies, which poses a human health risk for infants.
- Sludge may have a tendency to form a hard crust that may impede germination of some plants.
- During regional winter conditions, the soil surface is frozen, waste will not be incorporated into the soil, and it can create problems with spring runoff.

Storing Fish Manure and Aquaculture Sludge

Settled fish waste is generally in the form of a slurry that is around 95% water. While this high water content can be beneficial for direct land application, if further storage is necessary, dewatering of the sludge is likely to be necessary to

reduce the space required and to alleviate storage and handling costs. A study has found that a filter press with the aid of fly ash, agricultural lime, diatomaceous earth, or perlite reduced the moisture content and produced a filter cake material that retained 95% of the nitrogen, phosphorus, and biochemical oxygen demand, while reducing the moisture content of the waste by about 35%. Preliminary attempts to assess the utility of the filter cake material as a fertilizer for plant growth were not very promising. Although the filter cake contained nutrients, the amounts present or their availability did not compare to similar volumes of inorganic fertilizer, causing decreased growth rates. The fine particle size of the filter cake may have decreased pore space of the growth media, reducing growth rate. The high pH of the agricultural lime used in the filter cake material may also have been detrimental at the incorporation rates used.

Composting

Conventional composting is an accelerated breakdown of organic matter passing through a warming stage (113 to 149° F) where microorganisms liberate heat, carbon dioxide, and water. The poorly mixed organic material is transformed into a well-mixed and stabilized humus-like product through turning or aeration. Conventional composting is conducted by adding high carbon content materials to wastes of high nitrogen content and piling the mixture high enough (approx. 4 ft. in our region) to retain heat that supports the warming reaction. To avoid poor conditions and associated odors, these piles must be turned frequently for adequate aeration.

Composting helps to stabilize the waste material, and it reduces odors, the biological oxygen demand, and the volume of the waste.

Compost waste to produce a valuable stabilized soil amendment or planting medium that provides both a slow-release fertilizer and increased water holding capacity.

Composts have a commercial value and can potentially be sold as a soil amendment. Compost micro flora have been shown to have plant disease-suppressive qualities. Composting is also suitable for processing fish mortalities, spoiled feed, and fish processing residues.

Compost waste for easier storage and transport, and so that application can be delayed for better coordination with crop needs.

Potential constraints on composting involve storing wastes for considerable time and extra expense before they can be used. The conventional compost pile requires considerable bulk in order to retain the heat required for the thermophilic reaction, and in our region outdoor composting is subject to reduced activity during the cold season.

Vermicomposting

 Vermicomposting provides an alternative to conventional composting. The use of worms in the composting process offers several advantages that may be appropriate for further treatment and use of aquaculture sludge.

- Vermicomposting is a breakdown and stabilization process of organic material that, in contrast to conventional composting, involves the joint action of earthworms and microorganisms.
- Vermicomposting does not depend on a warming stage. The earthworms are the agents of turning, fragmentation, and aeration, which eliminates the labor associated with the turning of bulky conventional compost piles.
- Vermicomposting beds are typically only about 18” deep rather than the approximately 4 ft. depth needed for heat retention in conventional composting. Consequently, the space requirements are more modest, and the process can be effectively conducted on a scale from small household bins to large institutional waste disposal.

Vermicomposting end products are the worms themselves (sold as bait) and a highly valued organic soil amendment with excellent texture and moisture-holding properties. There is evidence that worm composting improves the availability of nutrients to plants. Earthworms can break down a wide range of organic wastes and are commercially bred on a large scale in organic wastes for fish bait. Currently, other livestock manures are used as feedstock for worms, and there is reason to believe that recovered aquaculture biosolids in the form of fish manure, unused feed, and fish processing waste could be effectively processed through vermicomposting.

Potential constraints on vermicomposting include storing wastes for considerable time and extra expense before they can be used. Outdoor composting is subject to reduced activity during our regional cold season.

Vegetative Methods for Utilization of Dissolved Nutrients

 Where possible, divert dissolved nutrients to stimulate beneficial plant growth, avoiding discharge to situations that promote detrimental algae blooms or weeds.

- Too few dissolved nutrients in water bodies results in low biological productivity and limited fish production.
- Excessive nutrients in aquatic systems can contribute to eutrophication and stimulate undesirable algal blooms and cause wide swings in microbial decay and oxygen depletion problems.
- Production of field and garden crops often requires addition of fertilizer beyond what is available in aquaculture waste.

The use of aquaculture effluents for crop irrigation has serious constraints and may only be valuable in special circumstances. Because aquaculture operations of a flow-through or outdoor pond type tend to be sited where water is abundant, it may be unlikely that they are sited near sites with a high demand for irrigation. Also, the timing of water discharge from aquaculture facilities is not necessarily going to correspond to the water demand for irrigation. Because effluents contain potentially elevated levels of nutrients, they may seem to have fertilizing properties, but the highly diluted nutrient levels in effluents usually mean that only the water itself and not its nutrient content is of practical use for crop growth.

Constructed wetlands or vegetative buffer strips are designed to treat effluents by filtering solids and potentially utilizing excess dissolved nutrients. They can alleviate water quality problems and protect or improve natural habitat. However, for aquaculture rearing methods with high volumes of dilute nutrient effluents, large areas are required to achieve hydraulic residence times sufficient to recover and utilize the nutrients. Costs of construction and restrictions of land availability can limit the application of these techniques.

Aquaponics

Aquaponic (hydroponic) soil-less greenhouse culture of vegetable, herb, and fruit crops can be a means of using dissolved nutrients from RASs, since in these systems higher concentrations of nutrients build up in the rearing water. In this context, crops are produced for profit as well as to remove nutrients from the rearing system. The combination of fish production with vegetable crop production requires sophisticated knowledge of fish biology and rearing systems, as well as knowledge of the plant growth requirements and hydroponic systems.

- Optimum plant and fish rearing conditions tend to differ enough to make the combination of the two in aquaponic systems less than ideal for each when grown separately.
- Temperatures ideal for fish can be too warm for certain vegetables.
- Typical RAS wastes contain insufficient quantities of certain macronutrients and micronutrients for plant growth.
- Chemotherapeutics used to control fish pathogens can kill plants, and pesticides used to control insects can kill fish.
- The value of the vegetable crop can be much greater than the value of the fish crop produced, which can place most of the focus on vegetable production to maintain profitability.
- Most commercial aquaponic systems have been relatively small operations that have serviced niche markets.



4.1 Collected samples of various fish species.
Jeff Miller, UW-Madison

4

Aquaculture fish health

by Myron Kebus

Overview

Import of fish, naturally and by people, presents the greatest risk of disease spread and *pathogen* introduction.

- Fish migrate naturally and may travel from infected regions to uninfected regions.
- Commerce of live fish and fish eggs is a major economic activity.
- The risk of disease spread and pathogen introduction is greatest in hatcheries that receive fish from many regions and stock most widely.

Aquaculture, state-supported and private, can impact fish populations in public waters. This can occur by disease spread or amplification of pathogens. Whether a hatchery is state-supported or private, the fish health standards must be uniform and science-based.

Conversely, pathogen transmission from fish in public waters can adversely affect cultured species.  **The health status of brood fish and forage fish acquired from the wild and introduced into hatcheries should be subject to stringent health assessments.** Unintentional introduction of infected fish or fish pathogens can occur from many sources, including fish entering in surface water and birds and aquatic organisms harboring infective material. Hatcheries should employ appropriate measures to reduce the risk of infected aquatic organisms entering hatcheries. *(figure 4.1)*

The risk of introducing disease depends in large part on the type of aquaculture facility (RAS, raceway, or pond), the health management practices, and stocking practices.

- Fish reared in public waters (e.g., net-pens) are at greater risk of introducing pathogens to public waters or receiving pathogens from public waters than are self-contained hatcheries (e.g., indoor RASs).
- The greater the level of health assessment and disease testing, the lower the risk of unanticipated disease outbreaks.
- Hatcheries that stock public and private waters have an increased risk of introducing fish disease compared to hatcheries that do not move live fish from their hatchery.

Additionally, chemical control and treatment of potentially pathogenic organisms can impact public waters. **The decision to use chemicals to fight fish disease should be done only after very thorough and careful consideration.** Shotgun treatment, treatment with multiple chemicals in an effort to treat a disease that has not been accurately diagnosed, should never be practiced. There is far greater opportunity to damage fish and the environment with this approach than to benefit fish health.

Fish disease treatment should rely heavily on improving management and husbandry, whether chemicals are used or not. Many fish diseases can be corrected without chemicals. There are some cases in which chemical treatment is essential. Producers are responsible for using chemicals in a legally approved manner. **Aquaculture veterinarians should be consulted for professional guidance on chemical use in fish hatcheries.**

We lack sufficient knowledge of the current distribution of pathogens in the Great Lakes region, factors affecting pathogen transmission, associated risks of various diseases to fish populations, and management strategies to minimize and avoid pathogen impacts in aquaculture and public waters.

- In general, we have more information on diseases of trout and salmon compared to other species.
- However, recently we have increasing information on diseases of many species, including channel catfish, yellow perch, largemouth bass, and lake sturgeon.
- Additionally, ornamental fish species typically raised in home aquariums are now recognized as potential carriers of pathogens that could contribute to disease in hatchery and wild fish. The opportunity for contact exists yet remains apparently low in most states.

Increased attention to surveillance and monitoring of fish diseases is needed in our region. All species of fish must be considered when developing laws governing fish health. The costs and benefits of increased fish health efforts should be investigated and be accompanied by efforts to educate producers and consumers.

Hatchery practices can impact human health. The major categories are drug residues and other contaminants in edible fish products, antibiotic resistance, and zoonotic diseases. Hatchery practices directly affect the first two categories and are a great concern in the U.S. and worldwide. Consumers expect the fish they eat and provide for their family to be safe and wholesome. Foodfish producers and hatcheries that release fish that may be caught and eaten are obliged to ensure that the edible fish tissues are not tainted with chemicals or other contaminants. Zoonotic diseases are comparatively rare and mild compared to zoonotic diseases transmitted by other animals.

Nature of Fish Disease

Pathogens are an inherent feature among both wild and captive populations of fish. Multiple factors, such as the environment and the condition of the fish, affect whether fish will become ill, or diseased. Infection and disease are not the same. Infection is the invasion of a host by a pathogenic organism; this may or may not result in disease. Disease is the loss of a health condition and has characteristic signs and pattern of death loss (mortality) with a population.

Pathogenic organisms are commonly parasitic, bacterial, viral, or fungal. The vast majority of pathogenic organisms are microscopic. It is not reliable to make a diagnosis based solely on visual signs of diseased fish.

Signs of disease (e.g., fin erosion) are not specific for a single pathogenic organism, or even a single category (e.g., parasitic). Efforts to arrive at a diagnosis without the use of veterinary diagnostics, including microscopy, will most often result in an inaccurate diagnosis.

Fish Hatchery Practices

 **When fish health problems arise, contact the appropriate fish health experts in your state.** In Wisconsin, contact the Division of Animal Health, administered by the Wisconsin Department of Agriculture, Trade & Consumer Protection (DATCP).

Fish health problems arise whenever fish are raised.  **Prepare for problems and use BMPs to prevent the occurrence and reduce the severity of fish disease on your fish farm. Prevention practices should be emphasized over treatment.** Fish farmers are responsible for maintaining proper fish health for the benefit of the state's fish and waters, other fish farmers, and the livelihood of their fish farm.

Fish Health Regulations

The U.S. does not have official national standards for fish health. Fish health regulations in our region are a patchwork of state regulations with no single authority on fish health standards. Fish health standards vary significantly from state to state. Some states have two sets of standards, one for state-supported aquaculture and another, generally more stringent, for private aquaculture.

Legal authority for state fish health standards resides in agriculture agencies or resource agencies. Federal health standards apply to international movement of fish and are administered by the U.S. Department of Agriculture or the U.S. Fish & Wildlife Service (FWS). At a national level, the American Veterinary Medical Association has published guidelines for use in the development of aquatic animal health regulations found at <http://avma.org/scienact/asacregrs.htm>.

In Wisconsin, fish health regulations are intended to protect Wisconsin's fish and waters and consumers of farmed fish. DATCP administers fish health regulations. In Wisconsin, state-supported hatcheries and private hatcheries are required to comply with one set of fish health standards.

All hatcheries are required to:

- Obtain import permits
- Maintain required records
- Contact the appropriate authority when reportable diseases occur
- Use drugs and chemicals in a legal and judicious manner

Develop a Farm Fish Health Plan

 Have a plan prepared to avoid/minimize fish health problems and to respond in the event of a fish health problem. Recognize when you are beyond the scope of your knowledge and expertise and consult a professional if necessary. Have the professional help develop your Farm Fish Health Plan.

 Keep daily records of mortality to know what is “normal” vs the beginning of a disease.

 Begin by knowing who your state fish health contact person is and how to contact him or her. Your contact person may be an aquatic animal health veterinarian, certified fish pathologist, or university extension specialist.

 It is good to know what tests can be run at your state veterinary fish health lab. It may help to know of other labs, including those in other states, that may be able to run tests on fish and water samples. Your state fish health contact person should be able to help you locate the labs that can meet your needs.

 Finally, know who regulates fish health and contact him or her in the event of serious fish losses so that he or she can take actions to protect your farm, your state's aquaculture industry, and fish in your state.

Best Water Quality Results in Best Fish Health

Good water quality is paramount to good fish health. Follow the practices discussed in Chapters 2, 3, 7, 8, and 9.

- Poor water quality weakens the natural defense mechanisms of fish

- Poor water quality makes it difficult for fish to carry out normal body functions
- Poor water quality reduces feed intake and, as a result, health and growth

Never attempt to correct a fish health problem without first assessing and correcting water quality problems. Drug treatment may or may not be indicated. In the presence of poor water quality, corrective management efforts or treatments most often fail.

Best Nutrition Results in Best Fish Health

The best feed should always be used because it is best for the fish, the environment, and your profits. Feed must be properly stored to prevent deterioration. Some diseases are a result of inadequate nutrients, and the best food contains the nutrients that are needed for the fish to be healthy and strong. Good food accurately matches the fish's needs and is properly digested, which results in the least fecal matter and the best water quality.

General BMPs

-  Provide best water quality
-  Avoid over-crowding
-  Avoid over-feeding and under-feeding
-  Minimize stress
-  Remove dead fish immediately
-  Call for professional assistance early
-  Obtain the best fish stock
-  Invest in good facility design and construction

Biosecurity

Reduce the risk of the transfer of disease organisms to your farm. Strive to know that your fish are healthy and free of serious disease-causing organisms.

Avoid transferring organisms that cause disease.

Potential sources include:

- Organisms on fish from other farms
- Organisms on fish from natural waters
- Organisms transferred on equipment or water

Critical points

- Introducing infected fish
- Introducing equipment that harbors disease organisms
- Introducing water that harbors disease organisms
- Farm traffic that harbor disease organisms on their footwear (visitors) or motor vehicle tires

Disinfection Recommendations

Dead fish collection, storage and disposal

- No dead or moribund fish should be released into the water
- All surfaces that have contact with tissues and fluids of dead or moribund fish should be subject to strict disinfection

Personnel

- Require everyone to perform complete disinfection procedures upon arrival and before going to other fish farms and lakes and streams

Equipment

- Dedicate equipment to your farm, or disinfect it
- Properly clean and disinfect all equipment after each use
- Do not share equipment between sites
- Retire wooden equipment
- All surfaces that have contact with tissues and fluids of dead or moribund fish should be subject to strict disinfection

Boat traffic

- Boats should not move between farm sites, or they should be disinfected

Diagnosis

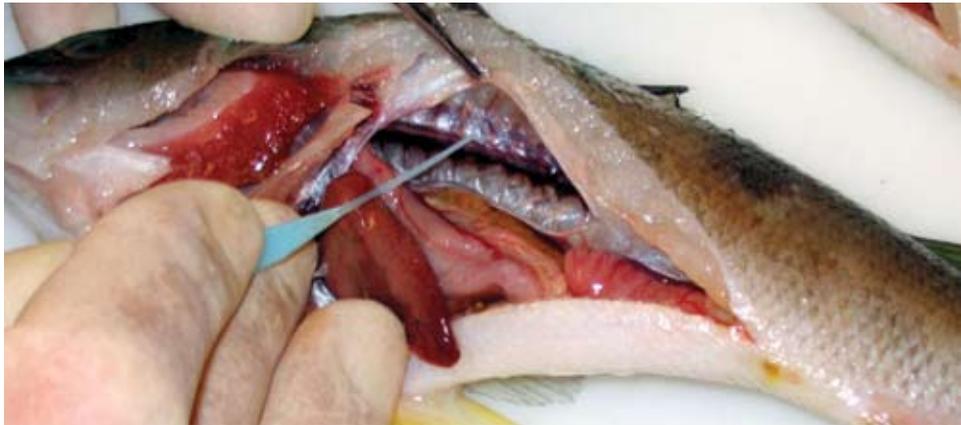
You must start with an accurate diagnosis. Arriving at an accurate diagnosis is a team effort that includes the farmer, the veterinarian, and the veterinary laboratory.

Reducing fish stress

Stress can impair growth, hinder reproduction, and contribute to fish diseases. Some helpful steps to reduce stress in fish include:

- Reduce human contact
- Prevent predators from harassing fish
- Modify methods of cleaning tanks to reduce stress, or use baffles for larger fish so raceways are self-cleaning
- Provide shade if rearing is outside
- Use 1% salt whenever handling/grading or moving fish

4.2 An assessment of fish health or disease often includes the sampling of internal organs or tissues.
*Myron Kebus, WI-DATCP,
 Division of Animal Health*



Drug and Chemical Treatment

There are indications for the judicious use of drugs and chemicals to treat fish or water. Fish farmers are responsible to comply with legal requirements and must be aware of the following items:

- Legal requirements for drug use for aquaculture
- Food safety/drug residue issues
- Legal requirements for chemical use for aquaculture

At the time of this writing, two important sources of information on the use of chemicals and drugs for aquaculture are:

<http://www.aquanic.org/jsa/wgqaap/drugguide/drugguide.htm>

and

<http://www.avma.org/scienact/asacregs.htm>

By federal law, drug users must follow Food and Drug Administration (FDA) labels on drugs.

By federal law, pesticide users must follow Environmental Protection Agency (EPA) labels on pesticides. A certified pesticide applicator license may be required.

5

Aquaculture and fish biology, species, strains & genetics

by Chris Hartleb

Overview

Temperature

Fish are *poikilothermic*, which means their body temperature is regulated by the temperature of their environment. Cultured fish are categorized into one of three general categories based on the temperature required for optimum growth:

Category	Temperature for Optimum Growth	Types of Fish
Cold-water	<60F	Trout, Salmon
Cool-water	60 – 75F	Perch, Walleye, Pike
Warm-water	>75F	Sunfish, Bass, Minnows

o.m.p Generally, the species selected for culturing must match the thermal range of the water that will be supplied.

- Within each range, the fish will have an optimal zone in which growth, feeding, respiration, and reproduction will be maximized. For example, brown trout can survive in water temperatures ranging from 34-77°F, with growth maximized between 45-63°F, feeding maximized between 40-65°F,

and respiration maximized at 65°F. Water temperatures slightly above those for survival will cause stress, and further beyond they become lethal.

- In the Great Lakes region, cold-water culture is generally accomplished in flow-through systems, or in pond systems in the northern portion of the region, where groundwater or stream water can provide cold temperatures for culture of trout and salmon.
- Cool-water culture often occurs in pond systems, where groundwater and surface water can be mixed to provide the appropriate temperatures for perch, walleye, minnows, and esocids.
- Warm-water culture can be conducted in RASs or pond systems, wherever warm water temperature can be maintained throughout the growing season. Species of sunfish, bass, and minnows are the most common warm-water fish to be cultured in Wisconsin.

Oxygen

Water is an oxygen-poor environment, with dissolved oxygen rarely exceeding 10-12 ppm (for comparison, oxygen concentration in air is about 300 ppm), so fish move large quantities of water across their gills to extract the oxygen they require. As water temperature increases, oxygen consumption by fish increases, while **oxygen solubility** decreases.

- **Oxygen deprivation** is the first factor to limit production in culture systems.

Temperature (°F)	Oxygen saturation (ppm)
41	12.8
50	11.3
59	10.1
68	9.1
77	8.3

- Supplemental aeration may be required as water temperature increases, or as the stocking density of fish in culture systems increases.
- In fact, supplemental aeration can be economically used to increase production in most culture systems by providing the oxygen needed to culture larger stocks.

Digestion impacts fish respiration to the point that oxygen consumption increases by 50% or more as digestion begins. Therefore, **if dissolved oxygen in the culture system is low, feeding should be suspended until additional aeration can be provided or oxygen levels increase.**

Metabolites

The major nitrogenous waste produced by fish is ammonia (NH_3), with salmonids producing 0.025-0.035 lbs of ammonia per pound of feed consumed. Beyond certain limits for each species, NH_3 becomes toxic and can cause large losses in culture systems. The continual flow of water in raceways flushes most wastes from the culture system, but this does not occur in ponds or RASs. In these systems, ammonia must be converted to nitrite and nitrate by bacteria present in the system. The conversion time is determined by the concentration of bacteria, water temperature, pH, total dissolved solids, and time of last feeding.

Intensive culture systems must be constantly monitored for ammonia levels and to check the efficiency of biofiltration components.

Elevated levels of dissolved carbon dioxide (CO_2) can result from overstocking, overfeeding, and inorganic carbon present in the water supply.

- High levels of carbon dioxide increase the blood acidity and decrease the ability of hemoglobin to carry oxygen in the fish.
- Elevated concentrations of CO_2 may sedate fish and become lethal.
- In flow-through systems the most common source of elevated CO_2 is the water supply.
- Groundwater that is not aerated and comes in contact with limestone becomes alkaline and has higher dissolved CO_2 levels.
- Pond and recirculating systems often have high concentrations of dissolved CO_2 due to intensive loading rates.
- RASs can have very high levels of dissolved CO_2 if proper ventilation to the culture room is not provided.
- Ambient CO_2 levels can increase as aeration tries to remove dissolved CO_2 from RASs, but this has the adverse effect of increasing contact and transfer between atmospheric and dissolved CO_2 .
- Aeration and alkaline chemical addition (lime, soda ash, or sodium bicarbonate) can be used to increase pH and decrease carbon dioxide in intensive culture systems.
- However, CO_2 levels should only be reduced to safe limits, since further removal can adversely affect water pH and the balance between atmospheric and dissolved CO_2 .

Fish Feeding

Fish require a balanced diet of proteins, lipids, carbohydrates, fats, amino acids, and minerals. Many culturists rely upon natural foods such as phyto- and zooplankton, while others use brine shrimp and yeast to feed young fish. Eventually, commercial diets can be fed to many species, with some accepting it early on, and others needing to be feed-trained.

- Commercial feed comes as floating, sinking, or neutrally buoyant.
- It is also prepared as microencapsulated, moist, semimoist, or dry.
-  **It is important that the culturist match the feed type and preparation to the species cultured and the culture system.**
- RASs and pond systems may be appropriate for floating and neutrally buoyant feed, but it may get washed downstream in a flow-through system, leaving the fish hungry.
- Feed preparation must be considered since moist and semimoist feeds require refrigeration, and microencapsulated feeds must mimic natural food characteristics.
- Many culturists select floating feed since it can be closely monitored by the farmer and may help determine feeding quantities and fish consumption rates.
-  **Fish feeding behavior should also be considered, and the appropriate type feed should be matched with surface, mid-water or bottom feeders.**

Nutritional requirements of fish must be met or developmental and health problems can arise. Specific diets have been created for catfish, trout, and salmon, but other fish can be fed diets manufactured specifically for omnivorous, carnivorous, or herbivorous feeders. As production of other species increases, feed manufacturers will most likely continue to develop additional specialized diets.

Nutrient intake by fish also influences waste and effluent production (see Chapter 3) and can have an impact on the health of the fish (see Chapter 4).

Food Conversion Ratio

The food conversion ratio (FCR) is determined by dividing the dry weight of feed offered in a given period of time by the wet weight gain.

$$\text{FCR} = \text{weight of feed offered} / \text{fish weight gain}$$

- Compared to other farmed animals, fish are efficient at converting feed into body mass with FCR values from 1.0-2.0 typical for trout.
- FCR tends to be lower in young fish and increases as fish get older.
- FCR values can be less than 1.0, but this usually means the fish are supplementing their diet with natural food items or are retaining excess water in their tissues.

Tip Frequent calculation of food conversion ratios by culturists can help determine feeding amounts and food utilization by the fish, or assist the culturist in determining proper feed quantities when changing feed types. The general rule is not to overfeed, and the FCR can help determine feeding efficiency.

Reproduction

Most fish species cultured in Wisconsin and the Great Lakes region are oviparous, thus allowing the culturist to collect the eggs and incubate them away from the parents. Gonadal development and spawning in most adult fish is regulated by changes in temperature and/or photoperiod. These changes can occur naturally, in grow-out or breeding ponds where eggs may or may not be collected by the culturist. Alternatively, in indoor systems the changes can be regulated to manipulate the timing of reproduction and spawning. In some fish species, the final maturation of eggs and spawning can be induced by injecting fish with spawning hormones such as LHRHa, or hCG.

Spawning is usually controlled by the culturist with egg stripping and milting accomplished by either the wet or dry method. (figure 5.1, 5.2) Exceptions include the centrarchids and cyprinids, which usually reproduce naturally with little intervention by the culturist.

- Fertilized eggs are often transferred to an incubation system, such as hatching jars, floating screens, or tray incubators, where the eggs develop over a period of days to weeks. (figures 5.3, 5.4)
- **Tip** Generally, quality water and consistent water temperatures must be maintained in the incubation system to increase egg survival.
- Water temperature manipulation can be attempted by calculating degree day temperature units, but appropriate incubation charts should be consulted so that water temperature stays within the tolerance limit of the species. Temperature units for each species are not fixed and will vary with water temperature, but they can be used as a guide to estimate the hatching date.



5.1 Dry Spawning.
Chris Hartleb



5.2 Wet Spawning.
Chris Hartleb



5.3 Hatching jars.
Chris Hartleb



5.4 Pouring salmonid eggs
into a tray incubator.
Chris Hartleb

- **omp** Eggs should be disturbed as little as possible, and low, incandescent lighting should be used when viewing the eggs.
- **omp** Degenerative eggs should be removed before fungi and bacteria appear, and eggs may need to be treated with a dilute formalin solution if contamination occurs.
- **omp** Culturists should consult a fish health expert before beginning any treatment of infected eggs.

Upon hatching, sac-fry (newly hatched young with yolk sac attached) are often transferred to small grow-out ponds or held in indoor culture tanks. Salmonids, which readily accept commercial feed, are usually maintained in indoor culture tanks and begin feeding once the yolk sac has been absorbed (fry). Percids and centrarchids are usually transferred to grow-out ponds, where natural food items, such as phyto- and zooplankton, are available and constitute the initial diet.

Once the fish have reached juvenile sizes, 1-3 inches, they are considered fingerlings and are frequently transferred to supplemental culture systems such as larger ponds, raceways, or larger indoor tanks where they may be feed trained, size-sorted, or stocked at appropriate densities. (figure 5.5)

omp As the fish grow they are often size-sorted and stocking densities are adjusted based on weight, number, feed consumption, and water temperature/oxygen requirements.

Age at maturity

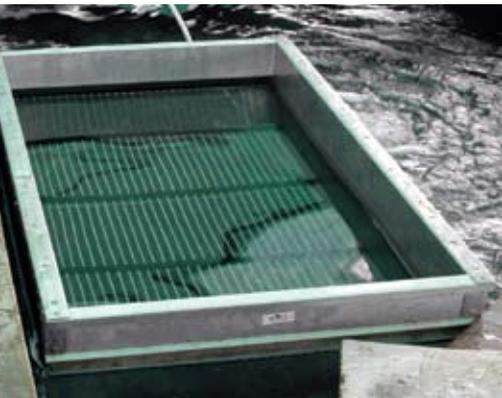
The reproductive cycle can be accomplished again when the adult fish have reached sexual maturity. The age at maturity varies with species; some salmonids are reproductively capable at one year of age, percids become mature at two years, and some minnow species are capable of reproducing within months.

Strains & Genetics

Currently, selective breeding (domestication selection) remains the primary method for culturists in the Great Lakes region to choose the inheritable traits for future generations in their stocks.

- Individual strains are created based on local or regional traits that improve the survival and marketability of each culturist's supply.
- Factors such as growth or survival improvement, flavor, disease resistance, reproductive capacity, color, shape, size, and nutritional value are the driving force behind strain selection and development.

Culturists must balance the selection of traits and not focus on immediate increases in production or farm management. **omp** **Farmers must remember that**



5.5 Floating fish sorter.
Chris Hartleb

selection for one trait is usually balanced with a negative effect on another equally important trait. Also, because farmed fish are domesticated and selected during reproduction, aquacultured species are known to have lower genetic diversity than wild populations. If cultured fish escape into the environment, they may affect the native fish through interbreeding and genetic pollution. The exact effects that interbreeding of cultured and wild fish may have on genetic diversity is not well known, but farmers should proceed with caution and safeguard against escapement.

Risk of escapes based on type of culture system can be listed as:

- Flow-through
- Pond
- Recirculating systems

with opportunity for escape decreasing down the list. Discharge type, drawn-down practice, and use of barriers to escape can have strong influences on the possibility of escape.  Use of settling ponds or discharge into wetlands can assist in the recapture or elimination of escaped individuals. Only completely closed RASs can guarantee that there won't be any escape of cultured fish.

In the United States, the majority of escaped cultured fishes have been from the aquarium (pet) trade. Fish that escape from aquaculture operations can be placed in two categories: 1) Exotic species that did not previously occur in the region, and 2) Cultured native species that occur in the same region as wild populations. The impacts that these fish can have if they escape into the wild include:

- **Genetic** — introgressive hybridization and interbreeding can result in genetic dilution, loss of diversity, or hybridization. Farm-raised fish that hybridize with native fish often display a loss of local adaptation and are at greater genetic risk.
- **Disease** — escaped fish may carry diseases into the environment or serve as hosts for new diseases. (See Chapter 4.)
- **Competition** — interspecific or intraspecific interference with native fish for food, habitat, or mates.
- **Predation** — escaped fish may prey on native species or attract other predators.
- **Habitat alteration** — escaped fish may change the native habitat or occupy space of native species. This disruption may reduce the amount of contiguous habitat available for population maintenance (breeding, adaptive capabilities, and increased local extinction).

- **Colonization** — escaped fish, especially exotics, may colonize local environments and change the existing biota.
 - For these reasons, culturists should establish a form of *inventory control* to keep track of their stocks and identify escapes. Some suggested steps include: *marking cultured fish* so they can be distinguished from native stocks, a *recapture plan* that varies in response to the size of escapement, and *careful monitoring* and *notification systems* so that escapes can be noted and responded to immediately. Generally, if an escape can be limited to very few fish, their impact on native species will be negligible since their genetic pollution will constitute only a minor fraction of the population’s genetic pool.
- Future methods for controlling the breeding ability and performance of cultured stocks through genetic engineering and transgenic fish are being investigated.
- Current emphasis remains on preventing interbreeding of cultured and wild stocks and avoidance of non-native introductions.
- Species or strains for culturing should be selected based on an inability to survive in natural environments or through techniques that produce sterile individuals.
- **Close monitoring of sterility, escapes, and trait selection must be conducted at each culture facility to prevent unwanted impacts on natural environments.**
- Local, state, and federal regulations that govern the importation, export, culture, transport, and sale of fish should be investigated prior to initiating any of the activities. Special concern should be given to non-native species prior to transporting them to any state.

In Wisconsin, there are regulations on fish importation and stocking that are aimed at controlling the spread of non-native species. These regulations are presented in Appendix II.

Selective Breeding

Selective breeding, or artificial selection, involves selecting mating pairs of fish that result in loss of genetic variability, but enhances specific attributes of the stock being bred.

- Criteria for selection may be based on growth, adult size, feed conversion, reproductive capacity, survival, color, or shape.
- Selection by the culturist may be influenced by the type of culture system—streamlined body shape may be chosen in a flow-through system, whereas

oblong body shape may be preferred in pond systems. Resistance to disease, both endemic and invasive, and market demand may influence selection; some strains are better suited for human consumption based on flavor, nutritional value and cut; and others are better adapted for stocking based on hauling tolerance and genetic conservatism.

The disadvantage to selective breeding is the overall loss in genetic variability that would have added to the health and future adaptation of the stock. Heritability, the portion of observed variation in a stock attributed to inherited factors, is generally low in stocks where mating of closely related individuals occurs. Inbreeding, or excessive selective breeding, occurs when too many related matings occur. Observed results include poor survival, reduced growth, developmental deformities, poor feed conversion, and loss of disease resistance.

 **Deleterious effects of selective breeding can be avoided if the culturist tries to maintain genetic variability in the broodstock.** This can be accomplished by either:

- Outcrossing, or outbreeding, in which distantly related individuals of the same species are mated. This can be accomplished by maintaining two or more breeding lines that are crossed during fertilization.
- Random mating, in which a large population of broodstock are maintained so that related matings are avoided. This can also be accomplished by sharing broodstock with other culture facilities that maintain independent brood lines.
- Rotational cross-line breeding, in which three broodstocks are maintained and breeding occurs between males (σ) and females (φ) of each independent line.

Hybridization

Hybridization, or the mating of two distantly related species, can result in offspring with increased growth, disease resistance, or tolerance to environmental stress. Heterosis, or hybrid vigor, is the term applied to the enhanced growth performance of hybrids compared to intraspecific mating. Common hybrids in the Great Lakes region include crosses between bluegill x green sunfish = hybrid bluegills, brook trout x lake trout = splake, brook trout σ x brown trout φ = tiger trout, northern pike x muskellunge = tiger muskie, walleye φ x sauger σ = saug-eye, and striped bass x white bass = hybrid striped bass.

Intraspecific mating usually produces a mixture of sterile and fertile offspring, and interspecific mating (hybridization) most often produces infertile (sterile) offspring.

-  There have been instances where interspecific mating of closely related species have produced fertile offspring, so reproductive capability should be checked before hybrids are released for stocking.
- Hybrid success can be influenced by which sex is selected during the mating. For example, successful tiger trout production will occur only if a male brook trout is crossed with a female brown trout.

Control of sex in populations

Many species of cultured fish exhibit differential growth rates between males and females. Being able to control the gender of a cultured population may also reduce the chances of interbreeding between wild populations and cultured fish. Many techniques have been used to produce monosex populations, including exposure to hormones during early stages of development or gynogenesis (the simulated fertilization of an egg by either a sterile sperm or a needle).

- Hormone treatment has been used to produce all-male populations of tilapia that show increased growth rates and reduced competition.
- Various methods of gynogenesis can produce an all-female population with the formation of a diploid (2n) egg that contains only the chromosomes from the mother.

In addition to the enhanced growth performance, there is some belief that production of a monosex population would allow the introduction of exotic species into new areas without the concern for natural reproduction occurring. Though only one gender from the introduced species is present, significant concerns still exist.

- Hybridization with a related species is still possible.
- Survival by gynogenetically produced populations remains low.
- Depending on the method used to create the monosex population, genetic tests have revealed some instances of paternal DNA present in the offspring.
- Monosex techniques have also been used as a means to limit reproduction in species that have been too prolific.

Triploidy

Triploidy is the production of fish with three sets of chromosomes (3n) and can be used to produce sterile offspring. Various chemical and physical methods have been used to produce triploid fish, including temperature, shock, and hy-

drostatic pressure and exposure to formalin shortly after fertilization. Triploid fish may exhibit increased growth rates when compared to normal diploid ($2n$) fish, resulting in increased fillet yield, but their inability to produce haploid ($1n$) gametes for reproduction has received the most attention.

- Examination of the gonads of triploid fish has shown abnormal gonads that produce few gametes, and those gametes produced are usually abnormal.
- Though production of triploids is usually 99% successful in making sterile offspring, quality control is still necessary since triploid fish released into the wild are usually non-native or genetically different from the local strains.
- The ploidy of each individual must be determined, and this can increase the cost of producing triploid fish.

Supplemental stocking of triploid fish into an ailing fishery is an additional option that some state fishery managers employ. Aquaculturists that produce triploids may find their stock resistant to some diseases, but early mortality is common in many triploid fish.

Transgenic fish

Genetic engineering, the transfer of genes from one fish species to another, produces transgenic fish that could outperform current strains of cultured fish. Molecular techniques could improve the growth rate, environmental tolerance, nutritional value, disease resistance, or reproductive potential of fish and it could greatly expand the fish culture industry. Currently, local, state, and federal laws strictly govern research in this field. Concerns about environmental impact, ethical issues, and ecological integration of transgenic fish prohibit the introduction of such fish into the wild. Further research and knowledge about gene control in fish and environmental consequences is needed before this area of fish culture becomes mainstream.



6.1 Fowler's toad. *National Park Service*

6

Aquaculture interactions with non-fish species

by Gary Casper, Jeff Malison, and Chris Hartleb

Overview

It is important to recognize the role of aquatic habitats in the landscape and how the presence or absence of fishes affects other segments of the community. Most aquaculture produces fish, and fish require resources (food and space). Adding an aquaculture operation to a landscape necessarily preempts space and food resources that had previously been used by other living things (nature wastes very little).

In many cases, aquaculture facilities add greatly to the diversification of wildlife and increase the number of wild organisms that depend on readily available water. For example, a growing segment of the aquaculture industry in the Great Lakes is the construction of ponds and other aquatic habitats in previously tilled upland areas. Clearly, such developments expand the areas available for organisms highly dependent on water or aquatic environments.

In other cases, (e.g., construction in wetland areas) aquaculture development may result in local declines of wetland-dependant wildlife, especially amphibians.

Adding fish to a landscape will also introduce a new food resource (the fish), attracting wildlife, which may be regarded as a nuisance by the aquaculturist.

 **One key to responsible stewardship is to ensure that aquaculture operations do not result in significant declines of other species.**

Effects of Outdoor Culture Facilities on Other Organisms

Amphibians

Amphibians are especially sensitive to some developmental and water use practices because of their limited mobility and the fact that fish are major predators and competitors. Habitat loss is the single largest factor contributing to amphibian declines, but habitat loss alone cannot explain all amphibian losses. Biologists have long known that some amphibian species cannot co-exist with fish, due to the competitive and predatory nature of fish. Appendix III describes in detail the tolerance of some amphibians to the presence of cultured fish.

Because of the importance of these amphibian species, new aquaculture development in wetland areas or naturally occurring water bodies should be done only after the impact of the proposed development on amphibian species is assessed.

Many amphibian species can co-exist with fish, through both behavioral (hiding in weed beds, sticking to shorelines) and chemical (poisonous and distasteful secretions) mechanisms to avoid predation. These species can be expected to increase with new aquaculture development. Some amphibians, such as tadpoles, can consume a significant amount of fish food in fingerling ponds and may compete with fish fingerlings for natural food. Amphibians can also be troublesome during fish harvest from ponds, since they are often the same size as the fish, and this may warrant further control techniques. A good source of information on frog and toad biology can be found at <http://wildlifedamage.unl.edu/handbook/handbook/allPDF/repf9.pdf>.

Frogs can be excluded or removed from culture ponds by trapping adult frogs before breeding season, removing emergent vegetation that is often used as breeding grounds by amphibians, and removing egg masses with a fine mesh net when they appear.

Plants

Many species of aquatic plants will grow in ponds and earthen raceways. Excessive growth of rooted aquatic plants and filamentous algae is usually detrimental to fish production. Such plant growth can be controlled by five primary methods:

- Management to minimize growth (e.g., water depth control, periodic draining, drying, freezing, tilling, compacting, etc.)
- Biological control
- Chemical control (herbicides)
- Mechanical removal
- Draining and freezing

(SRAC Publication 360 provides a good overview of managing aquatic plants.)

Other plants that thrive in wet or marshy areas, such as willows and cattails, will also proliferate in fish farms. Willows and cattails can be problematic if they overgrow along the levees and bottom of shallow ponds. These plants also remove a great deal of nutrients from water, however, and therefore they can be beneficial if located in aquaculture discharge/effluent areas.



6.2 Cattails or willows in a settling pond. *Chris Hartleb*

Invertebrates

Many species of aquatic insects are normally found in aquaculture waterways. Some species can serve to provide supplemental food for fish, while others can prey on small fish. **Pesticides, specifically larvicides, are available for pond application, but they should generally be avoided since they can negatively affect the fish and make the fish unmarketable. Often permits are needed to apply pesticides, and health and natural resource agencies should be contacted before pesticide application is tried. Abundant invertebrate populations can often be controlled through pond drawdown during winter months.**

Crayfish can proliferate in ponds used primarily for fingerling production. Crayfish can stir up bottom sediments, compete with fish for food, and damage and kill many small fish during harvest. **Intensive harvest (trapping) is the only recommended control method for over-abundant crayfish populations. Crayfish are not normally a problem in ponds used for large fish production, as their numbers are controlled by fish predation.**

Snails can be found in high concentrations in intensive fish farms. Snails consume detritus and therefore can help to clean pond bottoms. However, some species of fish parasites have a life cycle that flows from fish to snail to aquatic birds. High concentrations of snails can therefore lead to parasite problems in the fish.

Biological control of abundant snail populations can be achieved by stocking ponds with fish that consume snails, such as many sunfish species. Manual removal, which can be time and labor intensive, and winter pond drawdown are options when snail populations are abundant. Chemicals (molluscicides) are available to aid in snail eradication, but knowledge of their effects on fish is limited and they can make the fish unmarketable.



6.3 Snapping turtle. *National Park Service*

Reptiles

Numerous species of turtles are often found living in aquaculture facilities. Many species are not problematic, but some, such as snapping turtles, prey on fish and can damage nets and harvesting equipment. **The only recommended control of reptiles is trapping, since most reptiles are protected by state laws and rarely are they so abundant that manual removal is ineffective.**

Mammals

Fish-eating mammals, such as otters, mink, raccoons, and skunk are often attracted to aquaculture facilities. Although raccoons and skunk are not particularly effective fishermen, otters and mink can seriously damage fish populations in fish farms. Although muskrats and beavers are not piscivorous, their tunneling and construction can cause major damage to the levees and banks of ponds.



6.4 Muskrat burrow.
James A. Held



6.5 Wire or net bird control.
James A. Held

Trapping is the preferred method of small mammal control, though if the appropriate license is obtained, some elusive mammals may be hunted. The frequent presence of humans, and especially active dogs, can be a great deterrent.

Birds

The attraction of fish-eating birds to aquaculture facilities is a major problem for many aquaculturists. Cormorants, herons, piscivorous ducks, sea gulls, kingfishers, and other species can find frequent and easy meals at fish farms. **o m p** Noisemakers and cannons can be an effective short-term control method, but many birds learn to ignore these noises after a time. The use of netting over small ponds can be an effective control strategy but is not feasible over large areas. Wire or mylar tape strung across ponds at 15' intervals (5-15' above the surface of the water) can discourage some birds from flying beneath. At some facilities fish farmers have found unleashed dogs to be effective at keeping birds away. Ponds constructed with very steep side slopes can reduce the effectiveness of wading predators such as herons. A wire (sometimes electrified) or netting strung around the perimeter of a pond can control heron predation.

Herbivorous birds, including many ducks and geese, are also attracted to aquaculture facilities. Some of these birds, such as mallard ducks, can eat significant amounts of fish food. They can also scare fish at feeding time and, thereby, reduce fish growth. And as many people know, geese can be voluminous producers of fecal material. Several species of aquatic birds can act to spread fish parasites (see above).

Shallow wetlands, such as seasonally flooded basins, marshes, and ponds, are important for successful reproduction in many waterfowl, such as blue-winged teal, northern shoveler, gadwall, mallard, and northern pintail. These waterfowl feed heavily on wetland plants and associated aquatic invertebrates. Where fish are present, these aquatic invertebrate resources are largely consumed by fish. Like amphibians, many waterfowl have multiple habitat requirements, and maintaining sufficient availability of shallow, fishless, aquatic habitats is important to their continuing presence on a landscape. **o m p** Where aquaculture operations are planned, these impacts to waterfowl should be assessed, especially the impact to feeding and nesting habitat. State and federal permits are often required before birds can be removed from aquaculture facilities, and fish farmers should seek appropriate permits before deciding on a removal technique.

Other wildlife

Other than the special cases of amphibians and waterfowl, and to a lesser extent some shorebirds, crayfishes, crustaceans, and arthropods adapted to seasonal basins, aquaculture impacts to wildlife are generally neutral to beneficial. Exceptions include operations large enough that they replace a significant amount of natural habitat and where transfer of disease or parasites or pollution from effluents is a concern. The addition of ponds to a landscape often attracts certain wildlife, which may even become a nuisance to aquaculturists.

Generally, attracting wildlife into fish rearing ponds is not a desirable thing for the aquaculturist. However, certain amphibian and shorebird species may be benign from a production standpoint. If desired, ponds can be designed to promote these species by providing habitat complexity and shallow shelf areas where tadpoles can escape fish and shorebirds can forage during periods of low water. To achieve this, some separation from the main pond is required, such as a low berm. Alternatively, drain fields can be designed to hold water in temporary, shallow pools. This not only creates amphibian and shorebird habitat but also allows effluent to be filtered biologically before entering surface waters. Of course, effluent containing potentially harmful substances should not be made available to wildlife.

Nuisance control

Both state and federal regulations apply to the control of nuisance organisms pertinent to aquaculture. Wisconsin's regulations can be found in Appendix II.

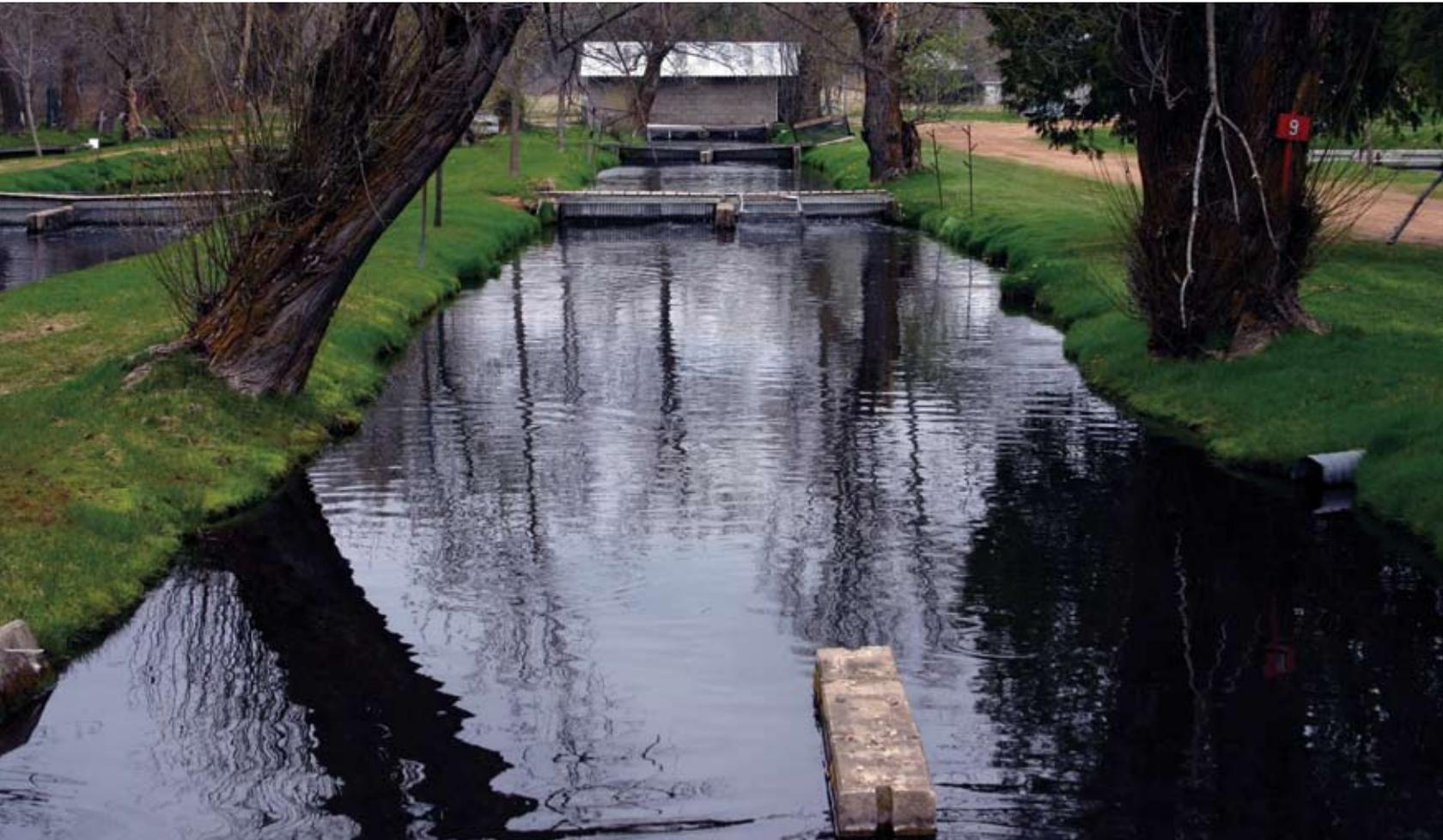
Construction of New Aquaculture Facilities

Aquaculture operations can have positive, negative, or no impact (neutral) on wildlife, but an assessment should be made prior to the construction of the facility. Impacts can be related to food resources, nesting habitat, predation, and competition, to name a few.

 A landscape level evaluation is suggested as one method for determining the impact of a constructed aquaculture facility on wildlife, where critical wildlife resources and likely impacts of the proposed aquaculture operation are locally evaluated. Other factors, such as habitat quality, may affect the response outcome, and consultation with a natural resource professional familiar with wildlife habitat requirements is recommended. Oftentimes, negative outcomes of development can be mediated or offset by creating new wildlife habitat (e.g., appropriately designed shallow wetlands within suitable upland habitat).

Aquaculture Within Public Bodies of Water

In Wisconsin, public bodies of water are seldom used for aquaculture. Exceptions to this include a small number of fish farms that have been “grandfathered” into current regulations, and the use of freeze-out ponds.



7.1 Earthen raceway. *Chris Hartleb*

7

Flow-through systems

by Chris Hartleb

Overview

Flow-through systems (commonly referred to as raceways) are culture environments in which water flow creates a current that can continually travel in a linear or circular direction.

Advantages of flow-through systems

- Continual flow of water replaces vital components such as oxygen, while removing potentially lethal components such as nitrogenous wastes and CO₂.
- Because of this replenishing system, raceways can support higher numbers of fish per unit space and can simplify harvesting, grading, disease treatment, and feeding.
- Concentration of solids and nutrients in effluents is often lower than that found in other culture system types.

Disadvantages of flow-through systems

- Large continuous flowing volumes of water are required, based on the size of the channels and fish production levels.
- Cleaning the waste that accumulates on the bottom of the raceway is difficult.



7.2 Concrete, parallel/series hybrid, single-pass raceway.
Chris Hartleb

- Removing effluent from high-volume, low-concentration discharge into receiving waterways is difficult.

Flow-through systems were traditionally constructed of earthen channels, but continual erosion has promoted the construction of raceways from more stable materials such as concrete, plastic, and metal. This chapter will primarily discuss the major flow-through systems in the Great Lakes region, which are designed in serial or parallel flow along with an accompanying settling pond. A few specialized systems, such as recirculating raceways and floating raceways have been constructed in this region, with the latter being discussed briefly in this chapter.

Species Selection

The choice of fish species to be raised in flow-through systems includes both traditional salmonids, such as rainbow, brown, and brook trout, and recent raceway culture species, such as yellow perch, walleye, and various minnow species. Since a general characteristic of flow-through systems is the continual supply of fresh, cold water, most salmonid production in the Great Lakes region is accomplished in raceways. Water for flow-through systems can come from two possible sources:

1. Groundwater, such as springs, artesian wells, and pumped wells
2. Surface water, such as diverted streams and drainage from lakes and ponds

Based on these sources, water temperature in flow-through systems in the Great Lakes region is usually $< 60^{\circ}\text{F}$ at the source, making flow-through culture ideal for cold-water species. Though alternative species, such as perch, walleye, and minnows are now cultured in flow-through systems, grow-out periods are significantly longer due to the colder water temperatures. Many culturists use flow-through systems as holding basins for cool-water and warm-water species, especially during depuration, periods of high consumer demand, or during winter when ice may form on ponds.

Indoor flow-through systems are infrequently used in Great Lakes fish culture for the entire growth period, but small-scale indoor raceways can be used as holding basins by many minnow species.

-  By placing the entire system indoors, water temperature can be increased through exposure to ambient temperature, and limited growth of warm-water fish, such as fathead minnows, emerald shiners, and white suckers, can be achieved.

-  Stock turnover should be frequent, with most fish spending less than three weeks in the raceway. Many culturists choose not to feed the minnows during this brief period, thereby avoiding effluent and raceway cleaning concerns. Those culturists who do feed the fish in the raceways must construct the system with supplemental aeration and settling ponds or filtration to account for the increased metabolism and waste production.

A more recent use of flow-through systems has been the construction of **floating raceways** (structural design explained later). Since these flow-through systems are suspended in ponds, water temperature is usually greater than 75°F in summer and is, therefore, usually best suited for warm-water species such as bass, minnows, and sunfish. Their use is limited to growing seasons of 150-200 days when ice is not present on the pond (April to October), since air pumps are used to create the water flow. Most culturists restrict their use to fry and fingerling size classes. This is due to a combination of restrictions on stocking densities and food availability where pond water, containing plankton, is pumped into the raceway and is often used as a supplemental food source.

Water Source

Compared with the other types of fish culture, flow-through systems require the greatest quantity of water. As mentioned earlier, water for flow-through systems comes from either groundwater sources, such as springs, artesian wells, or pumped wells, or surface water from streams or ponds.

- Springs or artesian wells are the preferred source since the water is of constant temperature (ranging from 44 to 52°F in Wisconsin) and flow; contains relatively few nutrients, pollutants, or nuisance organisms; and does not require a costly mechanical pump.
- However, spring water may be supersaturated with nitrogen and carbon dioxide gasses and have variable dissolved oxygen concentrations. These problems can usually be overcome by gravity aeration provided by flow over a levee (weir) or through a packed column.

An alternative water source choice would be a diverted stream, since water temperature is often cool (< 70°F in Wisconsin) and nutrients and pollutants tend to be minimal.

- Flow-through systems are susceptible to whatever nuisance organisms may be in the stream (including diseases), and permits are required to divert natural flowing water bodies.
- A Diversion Permit may be required (such as in Wisconsin) if the diversion of the stream results in an average loss of 3.09 ft³ per second during any 30-day period.

- Seasonal variation in flow, either because of winter icing or low flow in summer, should also be considered.
- **Prescreening and treatment of stream water is an option that may remove some unwanted organisms and allow for supplemental aeration, UV sterilization, and flow through a head water pond where suspended solids from the stream can settle out.**
- If trees line the outdoor raceway, a common method for regulating water temperature with shade, leaves frequently clog screens used in pretreatment. Considerable labor (>25% of daily activity) may be required, especially in the fall.

The least desirable water sources include pumped well water, which is costly and subject to mechanical failures, and diverted pond water (usually from a dam), which has large seasonal temperature fluctuations, may contain high nutrient levels and unwanted organisms, and often requires additional permits.

- **Surface draw or bottom draw may be used to stabilize the water temperature, depending on whether warm or cool water is desired, respectively. Bottom draw must be monitored closely for anoxia, and surface draw should be monitored for oxygen supersaturation from photosynthesis.**

Since the production of fish in flow-through systems is largely dependent upon the quality and quantity of water, careful monitoring of inflow must be constantly performed.

- **Dissolved oxygen must be monitored daily, since the size and number of fish in each raceway greatly influences the oxygen content.** On a per weight basis, smaller fish have higher metabolic rates and, therefore, greater waste production than larger fish. As fish grow and seasonal water temperatures fluctuate, these values can change rapidly.

7.3 Re-aeration of water in a raceway. *Chris Hartleb*



- **Re-aerating water as it enters the raceway is an inexpensive means to improving water quality for fish culture, and it assists the farmer in maintaining production (lbs/gal/min) and decreasing ammonia concentration, which often limits production in flow-through systems.**
- **Manage fish biomass within the carrying capacity of the system.** A common monitoring technique is to calculate the carrying capacity of the flow-through culture system by use of the flow index (**F**):

$$F = W / (L \times I)$$

where:

F = Flow index

W = Weight of fish in raceway in pounds

L = Length of fish in raceway in inches

I = Water inflow in gallons per minute

The flow index is derived by “trial and error” by either:

- Continually adding fish to the raceway with a uniform water flow until the oxygen content is reduced to the minimum acceptable level for the species (5 ppm for trout), or
- Keeping the existing stock of fish in the raceway and reducing the water flow until the oxygen content is reduced to the minimum acceptable level for the species.

Once the flow index is calculated for the raceway, the same equation can be used to predict the weight of the fish produced for any given size of fish or flow of water. Alternatively, the formula can be used to calculate the weight of fish that can be safely maintained in the raceway as fish length increases or water flow changes. Typical flow index values range from 1.0 to 2.5, depending on dissolved oxygen content and water temperature. A common form of the equation to calculate these applied techniques is:

$$W = F \times L \times I$$

where **W** is the weight of fish that can be safely maintained in the raceway and the other symbols represent the parameters described above.

Water Discharge and Solids Management

Flow-through systems discharge a large volume of water that contains dilute levels of waste products.

- Raceways typically flow into a settling pond, and the pond drains into surface water or groundwater.

- Most flow-through facilities discharge their effluent either into wetlands or into a receiving stream, depending upon proximity to surface-water systems and effluent levels. EPA guidelines and state regulations may require permits for effluent discharge. For example, in Wisconsin, a Wisconsin Pollutant Discharge Elimination System (WPDES) permit may be required to discharge aquaculture facility waste into surface water or groundwater. In addition, Wetland Permits may be required if impacts to wetlands may occur. Additionally, in Wisconsin, a Water Quality Certification (WQC) may be required if the wetland is a non-federal wetland.
- There are limitation guidelines and standards for the discharge of spilled drugs and pesticides, discharge of excess feed, maintenance of wastewater treatment systems, record-keeping and training of staff, reporting of experimental drugs, and development of facility-specific BMPs. Also, flow-through facilities must minimize the discharge of solids (uneaten feed, settled solids, fish carcasses) and may be required to use active feed monitoring and management strategies, limit wastewater discharge during transport and harvest, and prevent the discharge of dead fish in wastewater. EPA wastewater guidelines have recently been developed for commercial and noncommercial operations that raise fish and produce, hold, or maintain at least 100,000 pounds a year and discharge wastewater at least 30 days a year. Further details about the EPA guidelines can be found at www.epa.gov/guide/aquaculture.

bmp Generally, flow-through systems should employ an onsite settling basin, where suspended solids, excess feed, fish waste, and fish carcasses can settle out of the water before being drained into nearby surface water.

bmp Use of planted vegetation and proper construction of discharge can create backwaters that make removal of deposits easier and more efficient.

7.4 A typical raceway/
settling pond combination.
Chris Hartleb



omp A settling basin can also be used to regulate the temperature of the outflow water through surface or bottom draw. Outflow water should be monitored closely because bottom draw tends to siphon concentrated sediment from the pond bottom.

omp Periodic suctioning or draining of the settling basin allows for dredging of the settled waste, which can be spread on land or dewatered and used for fertilizer. Disposal procedures, including limits and locations, of solids and settled wastes from fish culture facilities is often regulated by local and state regulations. (See Chapter 3.)

Ammonia, the principal waste product of fish metabolism, is rapidly flushed out of raceway systems, usually before the ammonia is oxidized to nitrate. This can lead to low primary production (algal growth) in flow-through systems, but it can result in delayed nutrient enrichment when the effluent enters the receiving wetland or stream. Again, settling ponds help retain the ammonia long enough to accomplish the oxidation of ammonia to nitrate and nitrite, thereby reducing the enrichment levels of receiving waters.

Site Selection & System Construction

Flow-through systems are externally driven, and the quality of water, which has the greatest impact on fish production, is determined by flow rates, feed input, and dissolved oxygen levels. Three important factors to remember when designing a flow-through system include water quantity and quality, slope of the land, and effluent discharge location and management.

- **omp** When selecting a site for a flow-through system, the most important factor is a source of constant, large volumes of water that fluctuates only slightly in water quality both seasonally and annually.
- It is also important to consider the discharge of water from the facility, since state regulations may limit or preclude release of the discharge into pristine waterways. Receiving waterways may also be subject to numerical discharge limits set by individual states. During facility design, the culturist should include proper mechanisms for draining and diverting water. Benefits of complete draining and temporary diversion of water from all culture areas include ease in harvesting, cleaning, maintenance, weed removal, sediment removal, disinfection, and long-term fish health care.
- Minimum water volumes usually range from over 300 to over 1,500 gpm in each raceway unit. Therefore, when selecting a site, a combination of potential water source (springs, wells, streams, or ponds), continuous allowable draw, cost of moving the water, and discharge volume and location must be considered.

- Often, construction permits are required when building an aquaculture facility. In Wisconsin, water regulation and zoning permits are required when constructing a water channel within 500 feet of navigable water, placing an intake water structure in the bed of a stream, placement of a pipeline in the bed of a stream, and/or construction of a dam or water diversion.

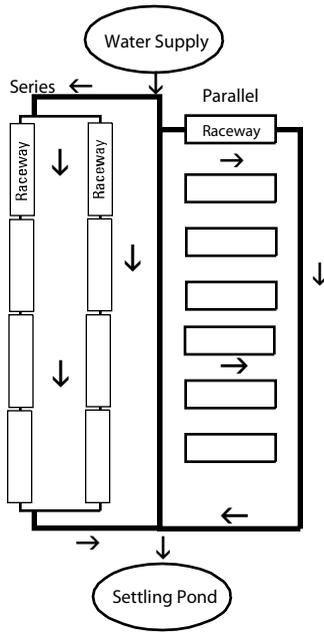
The type of flow-through system constructed depends on the land parcel size available, the proximity to the water source, and the type of water available. Three general categories of flow-through systems include:

- Single-pass raceways
- Recirculating raceways (discussed in Chapter 8)
- Floating raceways

Single-pass raceways

Single-pass raceways require large volumes of high-quality water at a rate of 150 to 500 gallons per minute. This type of raceway was traditionally constructed of earth (dirt), but more modern facilities construct the raceways of concrete, plastic, or metal. Concrete raceways are the most common, since they can be poured and shaped on-site to the layout of the facility and are the most durable and accommodating during harvest and transferring of fish. Polypropylene fabric (geotextile) anchored to the top and bottom of earthen raceways can create stable banks and is the most cost-effective material for construction. Rocks placed on top of the fabric will add durability and create a natural look.

- Raceways often have a length-to-width ratio of 6:1 for fingerling and adult size fish, but smaller ratios of approximately 3:1 are frequently used for smaller grow-out sizes and minnow culture.
- Water depth is kept at approximately 3 to 4 feet or less to allow for temperature stability, high turnover rate, and ease of cleaning and harvesting. Raceway walls are approximately 6 inches thick and can be constructed of steel reinforced concrete, especially if two raceways share a common wall.
- Raceway units are arranged in a tiered system with a 1-ft. drop between tiers for every 100 ft of raceway length. The drop allows for a 50% replacement of oxygen between units.
- Fish are size-sorted among units, with smaller (younger) fish located in the first unit and progressively larger (older) fish located in sequential units. This provides the smaller fish with higher quality water that has the highest oxygen content, a necessary arrangement since smaller fish have a higher metabolic demand per unit body weight.



7.5 The principles of parallel and series raceways.
Chris Hartleb

- Water flows via gravity between raceway units and eventually empties into a settling pond.

Two types of single-pass raceways are used in the Great Lakes region. The parallel raceway is a series of single-unit raceways constructed side-by-side, each usually fed from the same water source. Water enters each raceway from the spring, well, diverted stream, or pond and is balanced with dams or levees so that the same flow is achieved in each raceway unit. After the water has passed through the raceway, it enters the settling pond, before being discharged into the receiving water.

- Parallel raceways allow for independent feeding, waste treatment and, if necessary, medical treatment for each culture unit.
- The difficulty with parallel raceways is in achieving similar water flow in each parallel unit. Closely monitored and controlled dams, valves, and levees can assist in water management.

The series raceway is a tiered system of continuous flow culture units, where each unit flows into the next, sharing the same water from the beginning to the end of the serial system.

- Frequently, multiple-series raceways are constructed alongside each other, resulting in a parallel-series hybrid that allows for more culture units.
- Fish are size-sorted in series raceways so that smaller fish are at the beginning of the tiered system and the largest fish are in the last culture unit.

7.6 Splash boards and screening at the levee of a multiple series raceway.
Chris Hartleb



- Aeration occurs in the raceways as the water flows from one unit to the next (gravity aeration), with water exchange occurring once every hour (dependent upon flow rate).
- Layered wire mesh, PVC racks, or splash boards can be placed in the levee to increase aeration if low dissolved oxygen content develops.
- The outflow section of raceway units consists of a baffle preceding a screen that occurs 10 to 15 feet before the drop to the next raceway. The baffle creates an undercurrent that collects suspended solids in one section of the raceway (**quiescent zone**) where regular pump-cleaning can remove uneaten feed and fecal matter and the screen prevents fish from escaping to the next unit.
- Concern that fish will get trapped in the quiescent zone and that baffles make harvesting difficult have so far proven to be untrue for salmonid raceway culture. Salmonids tend to accumulate at the inflow end of the raceway, making attempts to jump into the next raceway unit. This keeps them away from the quiescent zone, but occasionally causes crowding and subsequent competition among the fish.
- Also, screens at the ends of raceways should be high enough to prevent fish from successfully jumping into the preceding raceway. As more species are raised in raceways, the effects of accidental trapping of fish in quiescent zones will have to be reevaluated.



7.7 Floating raceway with screening lids and automatic feeders. *Chris Hartleb*

Floating raceways

Floating raceways are long, narrow containers that are suspended in ponds with an airlift pump at one end to create the flow and a screen at the outflow end that prevents escapement.

- Water in the raceway comes from the pond and is, therefore, best suited for cool-water and warm-water species.
- The primary source of food for the fish is commercial feed that is dispensed manually or with automatic feeders. Supplemental feeding with zooplankton that are airlifted into the raceway may occur, but they are rarely present at the density needed to create a self-sustaining culture system.
- Since plankton can be airlifted into the system and commercial feed manually applied, floating raceways are best suited for juvenile or fry stages, or mostly planktivorous species, such as yellow perch and sunfish.
- Floating raceways can be designed as complex systems where the pond is fertilized for plankton production just before fish are added to the raceways.
- Effluents are discharged from the raceway into the pond and also provide fertilizer for plankton production.
- Floating raceways provide an easy mechanism for harvesting the fish, since the entire raceway can be seined or lifted from the pond. They also provide a convenient partly contained system for raising fish in ponds that may be too large to use as culture systems themselves.
- Disadvantages include reliance on mechanical air pumps that may break down, escapes by fish or predation by mammals or turtles, and disease transmission from wild fish that may be in the pond or among raceways that all rely on the same water source.
- Floating raceways are a relatively new technique that combines flow-through and pond systems to achieve high production densities in previously under-utilized large pond systems.

Water Quality

Fish raised in flow-through systems are raised at high densities because of the continual supply of fresh water and the well-oxygenated conditions. This stocking pattern leaves flow-through systems susceptible to pathogen transfer between tiered raceways since water is shared between culture units. If surface water (stream or pond) is used as the source water, pathogens can also be transferred

between the original water source and the raceway system. **OMP** Pretreatment, using UV-sterilization and filtration, may reduce the risk of pathogen transfer, but rarely can it completely eliminate natural pathogens.

Before drug or chemical treatments are considered, less expensive options should be tried, such as increasing water flow, reducing fish stress factors, and physically cleaning the flow-through system. However, if the pathogen problem cannot be solved with these methods, then judicious use of drugs may be the best treatment available. Before attempting pharmaceutical therapy, you should consult a fish health professional who can assist in the choice of drug or chemical treatment and properly administer the substances for the specific facility.

When treating infected fish in a flow-through system, additional calculations must be included to account for the dilution of medications due to the flow of water. **OMP** A well-designed system may permit the diversion, cessation, or recirculation of water flow, which, when coupled with supplemental aeration, can reduce the quantity of chemicals needed. Many of the drugs or chemicals are administered in a bath form that is dissolved in the water and subsequently very likely to leave the farm in the effluent discharge. When using chemicals in flow-through systems, we need not only consider the efficacy of the treatment but also the impact of the drug treatment on the receiving waters.

Fish Management

When compared to RASs and ponds, flow-through systems require the aquaculturist to feed the fish more often and with larger quantities of food.

- Since the fish are always swimming against a current, they expend greater amounts of energy that must be replenished by feeding.
- Dissolved oxygen levels must be maintained at higher levels than those of the other systems, since the fish require more oxygen for metabolism and stock densities are usually at high levels.
- **OMP** Efficient feeding practices should be established and based on the type of fish reared. Demand feeders may work for salmonids, while vibratory or hand-feeding may be more effective for cool-water species. Feed management should complement the design of flow-through systems where the water flow directs the excess feed to the end of the raceway into the quiescent zone or into the settling pond. Overfeeding will cause these areas to need cleaning more often and will increase the labor needed for suctioning or dredging the settled solids.
- **OMP** Another rule is to feed the fish often (up to 8-10 times per day), but underfeed at each interval, so that wastes do not accumulate rapidly. Close monitoring during feeding must be maintained, since dominant individuals often appear in the stock and consume most of the food.

bmp In flow-through systems, neutrally buoyant or sinking feed is usually preferred since floating food would be easily carried away with the flow. Demand feeders are the preferred choice, but most aquaculturists include hand feeding so they can monitor feeding activity and consumption. Feeding can be closely monitored because the water depth is rarely greater than 3-4 feet and, with good water quality, all the fish are clearly visible. Commonly, feeding is halted during the winter, especially when growing salmonids. Recent information has shown that salmonids will not accept commercial feed when water temperature is < 43°F but will continue feeding on live prey, such as minnows. If continued growth during the winter is required, a shift to live feed may promote limited winter growth of salmonids.

Harvest

Flow-through systems are designed for ease in harvesting based on the shallow depth and linear construction.

- Grading bars are used to crowd the fish to one end of the raceway, and seines or dip nets are used to lift the fish.
- Grading occurs often in raceways because individual fish grow at unequal rates due to dominance hierarchies and biased food consumption.
- By grading often, the aquaculturist can transfer faster-growing fish to down-flow culture units, thus disrupting social hierarchies and promoting faster growth of the remaining stock.
- Rarely do raceways have to be emptied, since cleaning, grading, harvesting, and spawning can be accomplished while the water continues to flow. Only during repairs do raceways have to be emptied, and at that time water flow can be diverted to other raceways or temporarily pumped to holding units.

7.8 Harvest of fish from a floating raceway using a seine. *News Services, University of Wisconsin-Stevens Point*



8

Recirculating aquaculture systems

by Steven Yeo

Overview

Recirculating aquaculture systems (RASs) allow most of the flow leaving the rearing tanks to be reused, and they concentrate wastes for easy removal.

RASs generally have > 95-99% reuse of their water. Summerfelt et al. (2002) and Chen et al. (2002) describe in more detail the wide variety of configurations and design variations currently employed in RASs. At a minimum, a fully recirculating system requires the following components:

1. Rearing unit(s) to hold the fish stocks
2. Clarifier or solids removal device employing settling and/or filtration methods
3. Biofilter for removal of dissolved nitrogenous waste (primarily ammonia and nitrite) by oxidation and detoxification
4. Aeration or oxygenation devices to add dissolved oxygen and remove carbon dioxide

8.1 Recirculating aquaculture system (RAS). *Chris Hartleb*





8.2 RAS biofilter.
Chris Hartleb

Additional water treatment equipment can include:

1. Advanced oxidation processes to disinfect and oxidize waste
2. pH controllers to add alkalinity
3. Heaters and/or chillers

Species Selection

- Fish reared by an RAS must have high market value and be reared rapidly at the highest densities to maintain cost-effectiveness.
- Only stress-resistant, hardy species with robust water quality tolerances are well suited for such high-density rearing in RAS operations.
- In the Great Lakes region, RASs are being employed for production of the newer alternative aquaculture species like yellow perch, tilapia, and hybrid striped bass.

Water Source

omp Groundwater and dechlorinated municipal water sources free from environmental contamination, parasites, and diseases carried by feral fish are recommended for RAS rearing.

Water Discharge and Solids Management

omp RASs employ water conservation and improved solids and nutrient recovery through closed, compartmentalized systems of culture tanks and water treatment units.

omp Because the wastewater and sludge produced by recirculating systems is concentrated to the point that its BOD is similar to domestic or municipal sewage, the operator needs an environmentally appropriate means of disposal or reuse of the material.

- Compared with other aquaculture systems, the volume of effluent is minimized and the concentration of dissolved nutrients is consequently much higher.
- Effluents of these systems have high enough concentrations of nutrients for the possible beneficial use of the wastewater flow for plant or vegetable production.

- It is generally with wastewater from an RAS that the attempt is made to couple fish production with hydroponics plant production (aquaponics). This further complicates the operation and requires additional energy input, but it can provide a second profitable crop that can potentially improve the economics of these systems.
- Because of its more limited total volume, wastewater from this type of rearing system can be more feasibly treated by a constructed wetland system or septic-type disposal system than rearing systems with large volume discharges.
- Recovered solid waste of low volume but high concentration can more readily be land applied or further composted and used as a soil conditioner and slow release fertilizer.
- Because they reduce water usage and avoid the discharge of large quantities of waste to public receiving waters, these systems are generally less apt to generate public water resource controversy.
- RAS rearing avoids the “dilution is the solution” approach. Instead of large amounts of diluted waste being foisted on public waters, the aquaculture operator is confronted with the problem of disposing of smaller, much more concentrated amounts of waste.

 Systems should be designed for effective rapid recovery of solids to avoid the tendency of solid particles to rapidly break down into an abundance of smaller sized particles, due to the turbulence of pumping, filtering, etc., typical of these systems. Smaller particles tend to remain suspended and become difficult to remove.

Site Selection and System Construction

- Lower water usage requirements and lack of climatic restrictions allow RASs to be constructed and sited almost anywhere that sufficient electrical power is available for system operation.
- RAS design and operation are more complex than those of other types of rearing systems, in terms of construction, operation, and maintenance.

Water Quality

- Water quality is critical in RAS operation, and dissolved oxygen, pH, and CO₂ and toxic ammonia and nitrite must be monitored closely.
- Because of the use of biofilters, there is generally a break-in period when it is necessary to build up populations of bacteria that break down ammonia and nitrite to levels that correspond to the waste levels produced by the fish to be stocked in the system.
- Because high densities of fish are generally involved, supplemental oxygenation and mechanical aeration are necessary. Mechanical aeration devices can also aid the removal of excess CO₂.
- Buffering compounds are added to counter the tendency of the water to become acidic with the build-up of CO₂ from respiration of the dense fish and bacterial populations.
- Salt is often added to provide chloride ions that counteract the effect of nitrite build-up and to reduce stress on the fish.

Fish Management

- Rearing temperature control can permit year-round production of fresh, quality-controlled product for markets at times and locations that would not normally be available.
- Fish are readily accessible for convenient handling and observation.
- Fish are less likely to escape or contaminate natural populations.
- Stress-mediated diseases with direct life cycles can spread easily in high-density rearing.
- Indoor rearing separates fish stocks from fish predators, vectors of diseases, and parasites with indirect and complex life cycles occurring in outdoor situations, including many tapeworms, yellow grubs, eye flukes, and certain protozoan parasites.



9.1 Typical pond culture system. *James A. Held*

9

Pond Systems

by Jeff Malison

Overview

Of the four general methods of commercial aquaculture (flow-through systems, net-pens, ponds, and RASs), pond culture is usually the most economical way to raise fish if the environmental requirements of a given species can be adequately met. Primarily because of this economic advantage, most aquaculture worldwide and in the United States is conducted in ponds.

The use of the term *pond culture* here is restricted to those ponds in which only enough water is added to ponds to keep the pond full — i.e., to make up for water losses through seepage or evaporation. It is important to keep in mind, however, that a significant amount of aquaculture is conducted in hybrid pond/flow-through systems, in which water is constantly flowing into and out of ponds to control temperature or other water quality parameters (e.g., DO or ammonia concentration).

Advantages of pond systems:

- Low density + low stress = fast growth + little disease
- Effluents can be contained
- Most economical

Disadvantages of pond systems

- Need large land areas
- Seasonal growth (except in tropics)

Species Selection

From an economics perspective, the choice of fish species to be raised is usually dictated by market; in other words, species are selected that can be sold at a profit. From a biological perspective, the most important criteria in species selection for pond culture is water temperature. Simply put, the temperature of a pond will dictate which species of fish will survive and grow well.

- Ponds in most locations have an annual temperature cycle that is dependent on the climate. For example, most ponds in the Great Lakes region are below 45°F from December through March and range from 65 to 85°F from June through September.
- The growth rate of fish is highly dependent on temperature, and accordingly, the growth of fish reared in ponds is seasonal and does not occur uniformly throughout the year.
-  **When considering species and climate, a primary goal should be to have water temperatures as near to optimal for the growth of the selected species for as many days of the year as possible.**
-  **A general rule of thumb for commercial aquaculture is that the growing season should be at least 180-200 days/year.** However, each fish species has a maximum temperature that cannot be exceeded for even a short period of time, or serious disease problems and heavy losses will occur. Some warm-water fishes also have a minimum temperature below which they can not survive.

In the Great Lakes region, only very deep ponds or ponds with a substantial groundwater input remain cold enough to raise cold-water species like trout and salmon throughout the year. Most other ponds will simply get too warm at some point in the summer to support cold-water fish.

- Cool-water fish, such as yellow perch, walleye, northern pike, muskellunge, and some species of baitfish, are probably the best-suited species for pond culture in at least the northern part of the Great Lakes region.
- For these cool-water fish, water temperature should never exceed 80-85°F. In Wisconsin, for example, well-designed ponds should be able to meet this criterion, and a growing season of 180-200 days is possible for cool-water fish, at least in the southern part of the state.
- Some warm-water fish, such as catfish and bass, can be grown successfully, particularly in the southern part of the Great Lakes region. But keep in mind that pond culture of warm-water fish is more economical in southern states, because of the longer growing season.

Water Source

Compared with the other methods of fish culture, ponds require a moderate quantity of water. On average, pond culture requires about 50 times more water to rear each pound of fish than RASs. In comparison, flow-through systems require about 50 times more water to rear each pound of fish than ponds. In order to estimate the amount of water needed for pond culture, keep in mind the following calculation:

At a continuous flow rate of 50 gallons per minute it will take approximately 22.6 days to fill a one-acre pond to a depth of five feet, assuming that no water is lost through seepage or evaporation and none is added via rainfall or runoff.

The two primary sources of water for ponds are groundwater and surface water.

- Groundwater or well water has the advantage of being at a relatively constant temperature (it ranges from about 44 to 52°F in Wisconsin); therefore, it can be used to cool ponds in the summer and to warm ponds and minimize ice build-up in the winter.
- Groundwater also contains relatively few nutrients, pollutants, or unwanted organisms. **Groundwater, or well water, should be tested prior to rearing fish to determine the levels of biocides and dissolved gases that may be present. Possibilities include pesticides, fertilizers, dissolved oxygen, CO₂, super-saturated O₂, hydrogen sulfide, methane, and iron.**
- In many or most locations, however, groundwater has to be pumped into ponds, adding additional expense.
- Permits are needed in most states for the operation of high-capacity wells (defined as > 70 gallons per minute in Wisconsin).
- Surface waters such as rivers and lakes can often be used without pumping, but they can vary greatly in temperature throughout the season and can contain unwanted chemicals and organisms. Prescreening of stream water (e.g., with series of screens or a rotating drum filter, or allowing the water to flow through and settle in a headwater pond) is an option that may remove some unwanted organisms.

A third possible source is the heated discharge from industry, particularly electric power generating facilities. Although this source has the potential to extend the growing season to 365 days per year, the track record of using such discharge for aquaculture in the United States has not been good.

omp Care should be taken when filling a pond because suspended sediments may make the pond unusable for weeks or nutrify the pond, resulting in algal blooms and depleted O₂ levels.

Water Discharge and Solids Management

Most commercial fish ponds discharge water from time to time, or at a minimum they must be drained occasionally, such as at harvest time.

- State and federal environmental agencies regulate these discharges. The newly developed (2004) USEPA discharge regulations do not apply to pond aquaculture facilities that discharge fewer than 30 days per year.
- The regulations may vary depending on the species and quantity of fish produced, the amount and type of nutrients discharged, and the water quality of the receiving waterway. For example, the regulations and restrictions for discharging into trout streams having outstanding water quality are generally much more stringent than for discharging into large warm-water rivers.
- Wetlands and crop lands can also be considered as potential sites for water discharge.

Regardless of the factors above, all new ponds should use the best reasonable management practices to minimize the discharge of potential pollutants.

omp In this regard, *settling ponds* are very effective at minimizing the chemical and biological effluents discharged from ponds, and they are also relatively inexpensive to build. Recent studies have also shown that long drainage ditches (situated between the pond drain and the site where the discharge enters a public waterway) can be very effective at removing excess nutrients and improving the water quality of pond discharges.

omp Over time, solids may accumulate on the bottom of ponds, settling basins, and drainage ditches, and it may be necessary to remove these solids. This is best done by allowing the land to dry thoroughly and then use earth-moving equipment to remove the solids. They should then be disposed of as discussed in Chapter 4.

Site Selection and Pond Construction

The land itself is an important consideration for selecting a site for pond aquaculture. Before discussing the relationship between land type and ponds, however, it should be emphasized that the *cost of building ponds* is often the largest single capital investment made in the development of a pond-based fish farm, more expensive even than purchasing the land. Accordingly, the cost of pond construction will have a major impact on the ultimate profitability of the fish farm. Pond construction costs are directly related to how much material must be moved and how often and how far it is moved. The cheapest way to move dirt is with a bulldozer or a self-loading pan (turnipull), and this might

typically cost \$0.75-\$1.50 per cubic yard. It is more expensive to use a backhoe, and it costs even more if the dirt has to be moved long distances with dump trucks. This can cost upwards of \$3.00-\$5.00 per cubic yard.

For any type of pond, plastic liners can be used instead of clay to prevent seepage, but pond liners typically cost \$10,000-\$20,000 per acre or more.

Ponds used for aquaculture in the Great Lakes region can range in size from less than 1/4 acre to more than 5 acres.

- Larger ponds are less expensive per acre to build, but ponds larger than 5 acres in size get progressively more difficult to manage.
- One problem with very small ponds is that water quality and other factors can change much more rapidly than in large ponds, which tend to be relatively stable.
- On the other hand, problem conditions that develop can be more rapidly corrected in small ponds than in large ones.
- **Normally, smaller ponds are best suited for raising fingerlings, small fish or bait fish, whereas larger ponds are better suited for growing large fish.**

The exact shape of ponds is often determined by the topography and property boundaries of the land.

- Most aquaculture ponds are constructed to be rectangular. Square ponds are somewhat less expensive to build than rectangles, but rectangular ponds, particularly for large ponds, are easier to manage.
- Ponds built for commercial aquaculture are generally shallower than recreational ponds, primarily to reduce construction costs. **If aquaculture ponds are going to be used all year long in northern climates, they should be a minimum of 7' deep.** This will help prevent winterkill and also reduce excessive warming during hot spells in the summer.
- **Pond bottoms should be smooth and have an adequate slope from the shallow to the deep end to allow for complete drainage and easy fish harvest.** **The outside slope of the pond bank can be 2:1, but the inside slope should be cut at a 3:1 slope.** Also, a spillway can be added to allow for overflow that may occur during excessive precipitation or ice-melt.

Resource agencies, environmental groups, and the general public have become increasingly aware of environmental problems that are being caused by the destruction or misuse of our country's natural wetlands. **At first glance,**

wetlands often appear to be well-suited for the construction of aquaculture ponds. Frequently, however, just the opposite is true. For example, aquaculture ponds built in wetlands are usually difficult or impossible to drain, leading to management problems. In addition, the U.S. Army Corps of Engineers, the USEPA, and various state agencies have strict regulations regarding construction in wetlands, and permits to build ponds may be difficult or impossible to obtain. Regulations that govern pond construction in Wisconsin can be found in Appendix II.

In some areas in the Great Lakes region, existing natural ponds and lakes can be used for aquaculture. The regulations regarding such usage vary greatly from state to state, and they should be closely reviewed before detailed plans are developed.

Land requirements vary greatly depending on the type of ponds to be built. From a construction point of view there are three general types of ponds:

- Excavated ponds
- Impoundments or watershed ponds
- Levee ponds

Excavated ponds

Excavated ponds are often built where the water table is close to the surface. They are made by digging a pit deeper than the groundwater level. Because they are dug below the water table, usually with a drag line or excavator, their size is typically one acre or less. The holes fill with groundwater by seepage, or water flows in from nearby springs. Less commonly, the pits are dug where they will catch runoff water from surrounding land or receive water diverted from a stream. Using some of the material removed from the hole to build a gentle berm around the pond can be helpful in diverting unwanted overland runoff.

Although excavated ponds are being used successfully for commercial aquaculture in Wisconsin, for at least two reasons they may not be the best choice for

9.2 Excavated pond.
Chris Hartleb



the fish farmer. First, excavated ponds are typically expensive to build because the equivalent of the entire pond volume in material must be moved at least once or more. Second, most excavated ponds are difficult or impossible to drain, thereby impeding a number of pond management strategies important to commercial fish culture.

Impoundments

Impoundments can only be built in specific locations, and they usually have an irregular shape, which can make them difficult to manage. Construction costs, however, can be quite low. Impoundments are currently used to raise fish in some parts of the country, but they are not commonly found in Wisconsin. Impoundments are usually formed by constructing earthen dams, and they are most appropriate in areas with significant land slope and tight soils. If possible, material is excavated from the area that will become the pond bottom to form the dam and deepen the pond.

- **It is best to have a site where a great volume of water can be stored by moving only a small amount of embankment fill.**
- The most desirable location is where the valley is narrow at the dam site, and the pond area is wide and flat but with steep sides.
- Excavation is usually required to deepen the site and provide the earth for the dam.
- Wave erosion on the dam embankment can be a problem in large ponds. **Try to choose a site where the prevailing wind doesn't blow along the length of the pond toward the dam if possible.**
- **Soils for earthen dams should be at least 20% clay by weight. The earth must be compacted to minimize seepage through the dam.** To ensure proper compaction, soil moisture must be controlled during construction.

It is better for pond quality to impound water from springs rather than from runoff or streams. Impoundments are not recommended if construction requires damming a stream. If created by damming a stream, they can become a settling basin for silt, sediment, and debris moving downstream. They fill in and become less suitable for fish. There is also virtually no way to control immigration of undesirable fish from the stream, making management extremely difficult. Damming of streams of any size is strictly controlled in most Great Lakes states and requires a state permit.

A properly designed impoundment will have two outlets for the water—a trickle tube or mechanical spillway and a vegetated earthen emergency

spillway. The emergency spillway is for flood flows. If the dam is properly constructed, watershed ponds can be drained, thereby enhancing fish management.

Levee

Levee ponds are the most common pond type used for commercial fish farming. They are well-suited for aquaculture because of their relatively low construction costs and because they can be built with regular shapes and a sloping bottom to permit complete and rapid draining. **The best locations for levee ponds (i.e., where construction costs are lowest) are flat areas with a deep layer of clay subsoil.**

- Levee ponds are usually built by removing 1-4 feet of material from what becomes the bottom of the ponds. The material is used to build levees around the perimeter of the ponds. The end result is that most of the water is contained above the original ground level.
- The levees should be at least 6 feet wide at the top and should extend at least 1-1.5 feet above the intended water level. **If possible they should be constructed with a 3:1 or greater slope.** The steep slope will reduce the area of very shallow water depth, which in turn will minimize weed growth.
- All vegetation (including stumps and roots) and top soil must be removed from the site prior to starting levee construction to allow a good bond between the foundation soil and fill material. Self-loading pans (turnipulls or scrapers) are the most efficient equipment to use in building levee ponds. They give the best compaction of fill material when complete wheel track coverage is made over each layer of fill placed in the levee.
- A PVC drain pipe of appropriate diameter (for example, a pipe at least 6-8" in diameter for a one-acre pond) is usually installed as soon as the pond bottom is graded. Fill materials are placed along the sides and over the top

9.5 Levee pond with plastic liner. *Chris Hartleb*



of the pipe and compacted to a distance of at least 12” above the pipe. This compacted fill provides protection from heavy equipment during completion of the levee.

-  **At least 2 anti-seep collars should be installed around the drain pipe.**

Several types of draw-down structures can be used—simple turndown pipes are recommended for large fish production, more elaborate structures with harvest kettles can be used for fingerlings or small fish, but these can be quite expensive.

-  **In northern regions, winter ice conditions should be given some consideration.** For example, if a simple turndown pipe is used and the pond is to be kept full during winter, aeration or continuous water input should be installed next to the drainpipe to keep ice from freezing around the pipe and heaving or breaking it.
-  **The drain system must be secure enough to prevent unintentional draining and large enough to allow the pond to be drained completely in 5 to 7 days, preferably fewer (e.g., a 6” pipe for a 1-acre pond and an 8” pipe for a 3-acre pond).**

The design of levee ponds minimizes the movement of material and thereby reduces the construction costs. In Wisconsin, suitable 3-5 acre levee ponds can be built for \$3,000 per acre and smaller ponds for \$5,000-6,000 per acre.

Water Quality

Oxygen and aeration

Most of the oxygen in pond water comes from gas exchange at the pond’s surface or is produced by aquatic plants and algae through photosynthesis. In addition to producing oxygen, however, plants also consume oxygen, particularly at night.

- Because of this, dissolved oxygen levels in a pond are always lowest in the early morning.
-  **One of the most important routine management procedures of pond culture is to regularly measure dissolved oxygen concentrations just before sunrise, particularly when potential dissolved oxygen depletions are anticipated.**
- Because of their high fertility, commercial fish ponds require more vigilance in oxygen monitoring than recreational ponds do.

Many types of mechanical aerators, such as paddle wheels, bubblers, etc., are used in pond culture. Some devices are used primarily to circulate the water in a



9.6 Paddle wheel. *Charles Graham, Star Prairie Trout Farm*

pond, others provide continuous active aeration, and others are of the stand-by type and are used only under emergency conditions of dissolved oxygen depletion. In general, intensive aeration devices are becoming more and more popular in pond culture because they can be used effectively to increase fish production per unit of volume or water usage. It is important to recognize, however, that most oxygen in a pond is not utilized directly by the fish but rather by bacteria, plankton, and plants.

• Aeration and water circulation systems provide several significant benefits to pond culture, some of which are as follows:

- Because of the large quantities of nutrients added to them, ponds used for intensive aquaculture occasionally suffer from dissolved oxygen depletion. During extreme situations catastrophic fish losses can result if remedial action is not taken.
- Without top-to-bottom water circulation, ponds will frequently stratify. This is especially likely in aquaculture ponds deeper than 3-4'. Although stratification can be desirable in recreational ponds to increase habitat variety, in highly fertile commercial ponds the water at the pond bottom will often become devoid of oxygen. Under these conditions, aerobic decomposition of waste products, which is essential for maintaining the high productivity of aquaculture ponds, does not occur.
- In northern climates, aeration can be used to keep ponds partially ice-free and to prevent winter kill.

Ammonia and pH

Ammonia build-up is not as severe a problem as oxygen depletion in most aquaculture ponds. However, ammonia levels can reach levels that cause concern —particularly when ponds reach high pH levels in mid-day or late afternoon, driven by high levels of photosynthesis.  **For this reason, occasional monitoring of ammonia levels and pH is warranted, particularly during sunny afternoons in late spring and early summer, times of long day-lengths and maximum photosynthesis.**

Water addition

At a minimum, some water must be added to aquaculture ponds to make up for that lost through seepage and evaporation. Several additional benefits can result when water flow-through is provided to aquaculture ponds.

- Water flow-through can be used to minimize ice formation and thickness in the winter.
- In summer, water flow-through can be used to reduce pond temperatures during hot spells.
- Depending on the amount of water available, flow-through can also be used to reduce the overall nutrient loads in ponds, thereby increasing production capacity.

One potential drawback to continuous water flow-through is that continuous water discharge will occur from the fish pond. Ponds having continuous discharge can potentially have a greater impact on receiving public waterways than ponds without flow-through, and they may be subject to more stringent regulations.

Fish Management

Feeding practices

Cardinal rules of aquaculture, regardless of system type, include:

-  **Never overfeed your fish.** Excess uneaten food increases production costs and can lead to impaired water quality and increased discharge of pollutants. An exception to this rule is with very small fish, which are sometimes fed more than they will consume.
-  **Another rule of aquaculture is to feed small fish frequently — as often as 6-8 times daily.** Most larger fish (> 4”) do not need to be fed more than once or twice daily.



9.7 Fish feeding at the surface. *Jeffrey A. Malison*

Imp In ponds it is usually preferable to use floating rather than sinking food. With floating food, one can easily observe the feeding response of the fish, and thereby reduce the likelihood of overfeeding. Some species of fish, such as yellow perch and walleye, will feed much more aggressively on floating food if the fish are fed during low light levels (dawn and dusk). In winter, when fish are less active and growth rates are low, sinking feeds are frequently preferred.

Fish diseases and treatment

Fish raised in ponds are usually held at far lower densities than fish reared in other aquaculture system types. Largely because of this fact, serious disease outbreaks are less prevalent in ponds than in other system types. The downside to ponds is that, if a disease outbreak does occur, treatment of the fish can be much more difficult or expensive because of the sheer volume of ponds.

Fish raised in ponds are susceptible to all of the infectious diseases (parasitic, bacterial, viral, and fungal) that are seen in fish raised in other systems. The most common infectious diseases tend to be parasitic diseases. Of the many parasitic diseases, the most common are the skin and gill parasites (*Trichodina* – protozoa, *Gyrodactylus* – skin fluke, *Dactylogyrus* – gill fluke) and the muscle parasites, often called flukes or grubs (*Neascus* – black grub, *Posthodiplostomum* – white grub, and *Clinostomum* – yellow grub).

Harvest

Several methods are commonly used to harvest aquaculture ponds. The only method by which ponds can be completely harvested is by complete drawdown coupled with seining or capture into internal or external catch basins. The use of such basins is usually restricted to small fish or fingerlings. Ponds that remain full can be partially harvested using seines, trap nets, or gill nets. A common technique to harvest large fish selectively from ponds is to use a size-selective seine in conjunction with partial pond drawdown. Regardless of the method used, it is important to recognize that harvesting procedures are very stressful to fish, due to physical and mechanical abrasions as well as rapid changes in water quality. If harvested fish are going to be kept alive, every effort should be made to minimize harvest stresses.

Imp For several reasons, commercial fish ponds should be completely harvested, drained, and allowed to remain dry for a period of time at least once every several years if possible.

- Complete harvest allows for the complete and accurate inventory of fish.
- This process kills or eliminates many disease organisms and other organisms such as snails, salamanders, and crayfish, which spread disease or can otherwise be detrimental to fish culture.

- The organic material that accumulates on the pond bottom will decompose quickly when exposed to air, or if the build-up is excessive, it can be mechanically removed.

Fortunately, most of the nutrients added to aquaculture ponds are assimilated by or remain in the pond during draining. Nevertheless, pond draining can result in the release of significant quantities of nutrients into receiving waterways. More study needs to be done to evaluate the quality of water discharged from different aquaculture pond types during draining, and to measure the effect of such discharges on receiving waterways. Generally, however, most studies to date have shown that pond discharges remain relatively high in water quality until the final 5-10% of the water is discharged. At this time, nutrients that have settled to the pond bottom can be disturbed and resuspended by the activity of the fish or personnel draining the pond. All efforts should be made to minimize disturbances to the pond bottom during final drawdown to reduce nutrient discharge.

Fish harvest is a key time during which there is a high risk of spreading disease or other organisms (including fish) from pond to pond. Great care should be taken to avoid such transfers. Specific steps that can be taken include:

-  **Thoroughly drying all nets, seines, and other harvest equipment before using them in another pond.**
-  **Disinfecting nets and equipment in a 1% sodium hypochlorite solution before using them in other ponds.**
-  **Maintaining discrete equipment used only in certain ponds containing the same stock of fish.**
-  **Treating harvested fish with a 1-3% salt solution to minimize stress on the fish and to kill external parasites.**

9.8 Fish feeding at the surface. *Jeffrey A. Malison*





9.9 Seining fish from a pond.
Chris Hartleb

appendix I. GLOSSARY

Biochemical oxygen demand (BOD). The amount of oxygen required for the biochemical degradation of organic matter.

Biofilter. A growth of bacteria colonies on a media surface over which water passes to remove nutrients and break down toxic nitrogenous metabolites in the water. Refers especially to the breakdown of ammonia and nitrite to nitrate.

Broodstock. Fish kept with the intention of using them for reproduction.

Carnivorous. Used to describe fish that feed exclusively on animals.

Centrarchids. Members of the sunfish family.

Clinoptilolite. A natural mineral that can be used as a water filter, usually to absorb ammonia.

Degree day. A measurement used to estimate and predict the various stages of fish development, especially during egg incubation. It is calculated by multiplying the average temperature by the number of days. For example, 300 degree days may be 30 days at 10°C, 100 days at 3°C or any other multiple that results in 300.

Diploid. Cells are normally diploid, meaning that they have two sets of chromosomes. A diploid fish is one that contains the normal number of chromosomes and has not been genetically altered.

Depuration. The process by which harvested fish are placed in clean, fresh water to allow for the purging of gastrointestinal contents and for aiding in the removal of "off-flavor" from the fish that may have resulted from biochemical processes in the culture system.

Drawdown. The process of slowly lowering the water level of a tank or pond.

Dry method of fertilization. The dry fertilization of fish eggs is accomplished by stripping the eggs into a clean, dry container. No water is included until after sperm is mixed in with the eggs. (Compare with "wet method of fertilization.")

Effluents. Waste liquids discharged from fish farms back into the environment or a treatment system.

Esocids. Members of the pike family.

Eutrophication. Water pollution caused by excessive plant nutrients.

Formalin. A clear aqueous solution of formaldehyde containing a small amount of methanol, used as an antiseptic, disinfectant, and a fixative for histology.

Genetic diversity. Variation at the level of individual genes (polymorphism). Genetic diversity provides a mechanism for populations to adapt to their ever-changing environment.

Genetic pollution. A weakening of wild fish populations as a result of genes from non-native, genetically modified, or cultured fish being dispersed with wild relatives.

Genetic variability. The result of random mutations that have accumulated gradually over millions of years.

Gonadal development. Development of the sex organs.

Gynogenesis. A process in which the egg is activated by sperm, but without fusion of the egg and sperm nuclei. This results in the development of an embryo with two maternal and no paternal chromosome sets.

Haploid. Having one set of chromosomes, i.e., the gametic number of chromosomes or half the number characteristic of somatic cells.

hCG (Human chorionic gonadotropin). A hormone that can be used to induce spawning.

Herbivorous. Used to describe fish that eat plants.

Heritability. The proportion of observed variation in a particular trait (such as intelligence) that can be attributed to inherited genetic factors in contrast to environmental ones.

Heterosis (hybrid vigor). The marked vigor or capacity for growth often exhibited by hybridized fish.

Hybridization. The process of producing hybrids.

Interbreeding. To breed within a closed population.

Intraspecific. Occurring within a species or involving members of one species.

Interspecific. Existing, occurring, or arising between species.

Introgressive hybridization. The transfer of genetic material between two distinct species by the production of fertile viable hybrids and subsequent matings of hybrids with members of the parental species.

Larvicide. A pesticide used for killing insects in the larval stage.

LHRHa (Luteinizing Hormone-Releasing Hormone agonist). A hormone that can be used to induce spawning.

Molluskicide. A pesticide used to kill mollusks.

Omnivorous. Used to describe fish that feed on both animals and plants.

Outcrossing (outbreeding). To cross one individual with a relatively unrelated individual or strain.

Oviparous. Producing eggs that develop and hatch outside the maternal body.

Oxygen deprivation. Lack of available oxygen.

Oxygen solubility. The amount of oxygen in water with respect to temperature (colder water has greater oxygen solubility).

Packed column. A method of aeration and gas stripping that consists of an open container with a great deal of surface area. Water flows over the material by gravity, equilibrating the concentration of gasses in the water to near saturation.

Pathogen. A specific causative agent of a disease.

Percids. Members of the perch family (Percidae).

Ploidy. Refers to the number of sets of chromosomes in a cell or organism. Most organisms are diploid, and sperm and egg cells are normally haploid.

Poikilothermic. An organism that has little or no control over body temperature, having a variable body temperature that is usually similar to the temperature of its environment, a cold-blooded organism.

Phytoplankton. Microscopic aquatic plants.

Salmonids. Members of the salmon and trout family (Salmonidae).

Secchi disk. A disk that is used to measure the transparency or clarity of water.

Solubilizing. To make more soluble.

Supersaturated. Water that contains a concentration of a substance (usually a gas) greater than saturation. Containing an amount of a substance greater than that required for saturation as a result of having been cooled from a higher temperature to a temperature below that at which saturation occurs.

Sustainable use. Using a resource so that the resource is not depleted or permanently damaged.

RAS (recirculating aquaculture system). A rearing system that reuses water, employing clarifiers, aeration devices, and biofilters to maintain water quality. Water usage is generally restricted to making up losses due to evaporation, filtration, etc.

Therapeutants (therapeutic agents). Medications that are used to treat disease and not to promote growth.

Transgenic. Having chromosomes into which one or more heterologous genes have been incorporated either artificially or naturally.

Wet method of fertilization. The wet fertilization of fish eggs is accomplished by stripping the eggs from the female into a small amount of water and immediately adding sperm. (Compare with "dry method of fertilization.")

Zoonotic disease. A disease transmitted from animals to humans.

Zooplankton. Microscopic aquatic invertebrates.

Wisconsin Department of Natural Resources Guidelines for Aquaculture

Regulations on Water Use in Wisconsin

Groundwater

1. New Wells

Section NR 812, Wisconsin Administrative Code requires a high-capacity well approval if a well is designed to pump more than 70 gallons per minute (GPM), which is equivalent to more than 100,000 gallons per day. The pumping and/or flowing capacities of all wells located on a contiguous property are added together to determine if the combined capacity of all wells on the property is in excess of 70 GPM. If the combined capacity of all wells on a contiguous property is over 70 GPM, the property by definition is a high-capacity property and operation of any well located on that property must be approved by the department. Pumping capacity is defined as actual flow rate or as the maximum GPM the pump will deliver at the lowest system pressure setting on the pump performance chart.

Prior to 2004, the only restriction for approval of a new high-capacity well was that it would not draw water away from any municipal well. The new groundwater law directs the Department of Natural Resources (DNR) to review environmental consequences of proposed high-capacity wells in certain situations:

- within 1,200 feet of any surface water identified as an “outstanding resource water” (like a pristine lake), an “exceptional resource water” (like a wild river), or a trout stream;
- a well that has a water loss of more than 95 percent of the water withdrawn (like a beverage bottler);
- any well that may significantly affect a spring that has a minimum flow of one cubic foot per second for at least 80 percent of the time.

Prior to approval of any new high-capacity well application, DNR will review the hydrogeology of the site to determine if these conditions are met.

For more information and an application form for high-capacity wells, go to <http://www.dnr.state.wi.us/org/water/dwg/hicap.html>.

2. Existing Groundwater Sources

If an applicant applies for construction of another well and the total withdrawal on the property exceeds 70 GPM, the property is then a high-capacity property, and all wells must be brought up to code.

Springs that have been altered to enhance flow by installing a pipe or some type of structure that meets the definition of “well” will have to meet the well design standards. A well is defined as any drillhole or other excavation or open-

ing deeper than it is wide that extends more than 10 feet below the ground surface constructed for the purpose of obtaining groundwater.

Springs that have been altered to stabilize the soil and/or enhance the flow by using structure such as concrete or stone but do not meet the definition of “well” are not required to meet the well design criteria. The spring water flow is not counted as part of the total pumping or flowing capacity of all wells when determining if the property will be defined as high capacity.

Basic design standards for all wells are:

- The watertight well casing pipe for all wells shall terminate at least 12 inches above the established ground surface, except that for wells in floodplains the top of a well shall terminate at least 2 feet above the regional flood elevation.
- The minimum distance between a well and a fish pond, lake, river, stream, ditch, or stormwater detention pond is twenty-five feet.

Surface Water

Fish farms that withdraw surface water to raise fish and then return most of the water to a stream can withdraw up to 2 million gallons per day (MGD) of surplus flow from a navigable lake or stream without a permit. However, a basis legal restriction is that any withdrawal cannot interfere with the public rights in the navigable waters, the rights of the public, or the rights of the downstream users.

A fish farm should be able to withdraw an adequate quantity of water from large streams with good water flow. However, the actual quantity of water that can be safely drawn from surface waters will depend on several factors:

- The percent of water being withdrawn compared with the total water flow, with the lowest percent being best
- The fish, aquatic life, and aquatic plants downstream of the water withdrawal that might be negatively affected
- Recreational and other uses in the stream downstream of the water withdrawal point
- The distance from where the water will be withdrawn to where it will be returned to the stream
- The change in temperature of the water as it flows through the fishponds or raceways
- The required water level in the stream to protect the public rights

If a farm requires more than the surplus flow or more than 2 MGD, the owner must obtain a Chapter 30 diversion permit and obtain consent of all downstream waterfront owners that may be adversely affected.

The method used to collect and transport the water to fish ponds or raceways may require a permit:

- Gravity flow—If the water source is upgradient of the fish farm, the water can be collected in a pipe that flows downhill to the fishponds or raceways. You may need a permit to construct a permanent intake structure in the waterway.
- Pumping—To move water uphill or longer distances, a pump can be placed within the water source. A permit may be required under Section 30.12, Wisconsin Statutes for the placement of the pump or other device on the bed of the water body. Depending upon the construction of the diversion equipment, a dredging permit may also be required.
- Constructing a dam—In situations where the water is very shallow, a dam may be desirable to collect the water into a larger and deeper pool. If you propose to construct a dam in order to create a pond to withdraw water for your fish farm, a Chapter 31 permit is required. Dam permits require extensive review to evaluate impacts to fish and aquatic life as well as neighbors upstream and downstream.

For more information on surface water withdrawal, check the Web at www.dnr.state.wi.us/org/water/fhp/fish/aquaculture/divwaterper.htm.

Land Application of Waste in Wisconsin

General Requirements

The U.S. Environmental Protection Agency's (EPA) effluent limits for aquaculture facilities are silent on land application regulations for wastewater and fish manure. However, Wisconsin regulates all land application of waste with a Wisconsin Pollution Discharge Elimination System (WPDES) permit. The criteria for the design and management of all types of land application systems that might be applicable for fish hatchery waste are included in NR 214 of the Wisconsin Administrative Code.

All land application systems depend on a suitable depth of permeable unsaturated soil to provide wastewater treatment as the water percolates through the soil structure. Some land application systems will include a plant component. The crop will utilize the nutrients, mainly nitrogen, phosphorus and potassium, for plant growth and prevent them from reaching the groundwater. For any waste discharged to a land application system, it is important to periodically collect and analyze a representative sample to measure the loading to the system.

The most important analysis is for the plant nutrients, and in those systems that utilize plant nutrient uptake, the annual application rate is limited to what the crop needs for fertilization. For some wastes, additional analysis, such as the solids and/or chloride concentration, is important.

Solid fish waste is rich in these important nutrients and a management system can be designed to produce a marketable crop.

The types of land application systems are distinguished by how the water is applied to the soil. It can be sprayed on, absorbed from a shallow ditch, absorbed from a pond, surface applied from a truck, or absorbed from subsurface distribution pipes. The appropriate design is dependent on the concentration of pollutants, the seasons of discharge, and the volume.

Spray Irrigation Systems

During the growing season the wastewater is applied to the fields using a type of irrigation equipment. One type of system is temporary piping laid out in a grid pattern that is moved periodically or that has nozzles that can be relocated, so that different areas of the field can be rested and loaded. Similarly, a trailer-mounted high-volume nozzle can be moved to different sections of a field. For higher volumes, the distribution could be done by a traveling gun system in which a wheel-mounted sprayer is pulled down a lane trailing a flexible rubber hose, and the waste is irrigated over approximately a 100-foot-wide strip. For these systems, a high-pressure pump driven from a tractor power take-off with a flexible rubber hose is often used. For very large volumes, a center pivot system could be used. In this system, the wastewater is pumped to the pivot point of the center pivot system, and the spray nozzles rotate around the field in a circular pattern, evenly distributing the wastewater.

All spray irrigation (SI) systems require that there be suitable soils and at least 5 feet of separation from groundwater and bedrock. SI systems must be at least 250 feet from a private potable water supply well and 1000 feet from community public water supply well. There is also a minimum separation distance of 500 feet from a neighbor's house. This distance can be reduced to 250 feet for your own home, or if you have the homeowner's permission.

The advantage of a SI system is that it can handle large volumes of wastewater, and the plants will take up the nutrients. The disadvantage is that they cannot be operated in the winter. A SI system would be well-suited for a system where ponds overflow or are drained in spring, summer, or fall but not in winter. An alternative would be to construct a wastewater holding pond to store wastewater during the winter months so that it can be applied by SI in the spring.

Hauling and Land Application

Similar to SI systems, hauling and land application (HLA) has the advantage of applying nutrients directly to the plants. This system might be applicable where the fish farmer does not own or have access to suitable land close to the farm. Waste from a holding tank is pumped to a hauling vehicle such as a truck or

tractor with a liquid manure spreader. The vehicle can be driven over the field to distribute the waste by gravity from a perforated pipe. Another method is to use a pump to spray the waste over the crops. With a high-pressure pump, the waste can be distributed without running over the plants.

The same minimum separation distances for SI apply to HLA, except that waste can be applied as close as 200 feet to a neighbor's home, if the waste is directly injected or incorporated into the soil and you have the homeowner's permission. The spreading field must have suitable soils and be at least 3 feet of separation to groundwater and bedrock. Maximum field slope is 12% in summer and 2% in winter.

The obvious disadvantage to HLA is that the volume that can be economically hauled is limited. Hauling and land application is most practical for handling concentrated fish waste. Solids collected from settling ponds and tanks and sludge generated from a water recirculation biological treatment system could be managed with this system.

Seepage Ponds

Seepage ponds are natural or man-made depressions in permeable soil where wastewater is discharged to percolate into the soil. The bacteria that live in the soil provide treatment. Since there is no nitrogen uptake by plants in this system, it is only suitable for wastewater that has low concentrations of pollutants. Generally this will be a flow-through fish farm system with good solids removal prior to discharge to the seepage pond.

The bottom of the pond must be at least 5 feet above groundwater or bedrock. The soils should have a permeable texture, such as loam. Coarse-grained soil structures, such as gravel, are not acceptable because the permeability is too high to allow time for treatment as the waste percolates down through the soil. The minimum separation distances from wells and homes are the same as spray irrigation.

Seepage ponds can generally be operated year-around. A pond design should not count on any water to evaporate because on an annual basis Wisconsin receives the same amount of rainfall as evaporation—30 inches per year.

Subsurface Soil Absorption

These systems are commonly used for household waste that is pretreated in a septic tank and then dispersed through an underground network of perforated pipes. With an adequate depth of moderately permeable soil, the wastewater receives final treatment by bacteria that live in the soil. The design of subsurface soil absorption (SSA) systems is detailed in Department of Commerce Code 83 and in their In-Ground Soil Absorption Component Manual. Loading rates are specified based on the wastewater pollutant concentration, soil texture, and soil structure and range from 0.2 to 1.0 gallons per square foot per day. SSA systems must be at least 50 feet from a private potable water supply well and 50 feet from a lake.

Although anaerobic treatment in a septic tank is the preferred pretreatment method for household wastewater, other methods may be suitable for fish farm wastewater. The minimum treatment is to provide a detention tank with enough residence time to remove all settleable solids.

One advantage of a subsurface soil absorption system is that it is a year-around system. A disadvantage is that the cost of construction per gallon of wastewater handled is high.

Ridge and Furrow System

This system consists of a series of parallel furrows, 1 foot deep and 1 foot wide, and located about 8 feet apart. A header ditch connects all the furrows and feeds the wastewater evenly into each furrow. A cover crop is planted on the ridges to take up water and nutrients. A properly designed system will have more than one cell so that the system can be rested and loaded, thus allowing the aerobic bacteria in the soil to degrade the waste. When wastewater regulations were first implemented about 30 years ago, ridge and furrow (R&F) systems were popular for cheesemakers and small dairy processors, and some are still in use today. Although there are currently no fish farms using an R&F system, their design should handle this type of wastewater.

The bottom of the furrow must be at least 5 feet above groundwater or bedrock with at least 3 feet of good soil texture and structure. The minimum separation distances from wells and homes are the same as for spray irrigation, except that there is no minimum distance from your own home or homes from which you have the homeowner's permission.

As with the subsurface system, to avoid soil plugging and overloading the system, the minimum treatment is to provide a detention tank with enough residence time to remove all solids.

Regulatory Requirements for Land Application Systems

The emphasis for wastewater management in a land application system is to implement the best management practices discussed in this manual throughout the fish farm operations. This includes good design and construction of a land application system with pretreatment components where necessary. A fish farm that uses BMPs in both the raising of fish and management of their land application system may be exempt from a WPDES permit or may be eligible for a general permit.

Please contact your local DNR wastewater engineer or wastewater specialists for more specific information. A list of DNR wastewater engineers and wastewater specialists by watershed basin can be found on the DNR's Web site at: <http://www.dnr.state.wi.us/org/water/wm/ww/wwstaff/staff.htm>.

Surface Water Discharge Regulations in Wisconsin

EPA Effluent Standards

EPA has delegated to Wisconsin DNR the authority to issue Wisconsin Pollutant Discharge Elimination System (WPDES) permits for all wastewater discharges to surface water. Wisconsin uses the EPA effluent standards to determine when a WPDES permit is required. Generally, the following facilities are required to have a wastewater discharge permit: facilities that discharge at least 30 days per year and produce more than 20,000 pounds of cold-water fish per year, facilities that discharge at least 30 days per year and produce more than 100,000 pounds of warm-water fish per year, and facilities that the department identifies as significant contributors of pollution to waters of the state. To date, the department has not identified any fish hatchery or fish farm as a significant contributor of pollution.

EPA recently revised the aquaculture point source category rules, and the revised rule became effective on September 22, 2004. The final rule applies to facilities such as fish hatcheries and fish farms that produce at least 100,000 pounds of fish or other aquatic animals each year. The rule covers flow-through, recirculating, and net-pen systems, but not ponds.

Rather than establishing numeric effluent limitations, the new federal rule requires permittees to implement BMPs to control the discharge of pollutants. The rule's BMPs include:

- Employing efficient feed management to minimize the discharges of excess feed;
- Regularly maintaining production and wastewater treatment systems;
- Reporting the use of experimental animal drugs and drugs that are not used in accordance with label requirements;
- Preventing discharge of drugs and pesticides that have been spilled;
- Reporting failure of or damage to a containment system;
- Training staff to properly operate and maintain production and wastewater treatment systems and to prevent and respond to spills;
- Keeping records on numbers and weights of animals, amounts of feed, and frequency of cleaning, inspections, maintenance, and repairs; and
- Developing and maintaining a plan that describes how the facility will meet the above BMPs.

The department continues to use its best professional judgment to establish technology-based effluent limitations for those facilities that produce between 20,000 and 100,000 pounds of cold-water fish per year.

Water Quality Based Standards

The new EPA rule does not alter Wisconsin's water quality based effluent limitations, effluent limitations for phosphorus, restrictions on groundwater discharges, and any related monitoring requirements. Water quality based effluent discharge standards are applicable to all fish farms regardless of the quantity of fish produced or the volume of the discharge. For all wastewater discharges, the DNR evaluates the impact on the receiving stream; there must be adequate flow to assimilate the discharge without changing the water quality of the stream. Small streams have less ability to assimilate pollutants and temperature changes that can result from fish farm discharges. Discharge to streams classified as "exceptional" or "outstanding resource waters" will have to be as clean as the stream water. Discharge requirements for trout streams are also very restrictive—to prevent pollution, including increased heat. Exceptional and outstanding resource waters are listed on the Web at www.dnr.state.wi.us/org/water/wm/wqs/index.htm.

Acquiring Fish for Farming in Wisconsin

Buying Fish from a Wisconsin-Registered Fish Farm

A DNR stocking permit is not required for a registered fish farm to buy fish from any Wisconsin-registered fish farm. The Department of Agriculture, Trade and Consumer Protection (DATCP) has developed health standards for fish stocked into waters of the state. However, fish farms are not considered waters of the state. In this case, the fish health standards do not apply. Fish stocking includes stocking fish from hatcheries or fish farms into lakes, rivers, and streams. However, citizens who would like to stock fish into a pond on their property or a lake association or fishing club that wants to stock fish in a lake or stream must obtain a stocking permit from DNR.

Importing Native Species

Regulations require an annual import permit to bring live fish or fish eggs from another state into Wisconsin for stocking into state waters, use as bait, holding or hatching on a fish farm, or sale or distribution for any of those purposes. A health certificate issued for that shipment or some other evidence of fish health must accompany each import shipment. DATCP administers the import permits and health regulations. See www.datcp.state.wi.us/ah/agriculture/animals/aqualwynk/import.html.

Importing Non-Native Species

Applications to DATCP to import a non-native species are referred to DNR for review, and if DNR approves the import based on ecological considerations, DATCP will issue an import permit. This is necessary because the intentional or accidental release of non-native species that compete for food and habitat with native species may have a detrimental effect on native populations. Generally the DNR will only approve the importation of non-native species that are not capable of surviving and reproducing in Wisconsin waters.

Although some of the more popular farmed species—rainbow trout, brown trout, Atlantic salmon, coho salmon, and chinook salmon—are not on the native species list, they are established in Wisconsin and their importation is routinely approved.

Capturing Fish from the Wild

Fish that are caught from waters of the state by angling can be stocked in a registered fish farm, including ponds, raceways or tanks, or a private fish preserve with these restrictions:

- a. All fish must be legal sport fishing catches
- b. The maximum stocked per year is limited to the sport fishing possession limit
- c. It is not legal to stock sturgeon
- d. Fish that are caught from waters by angling cannot be stocked into other waters of the state without a stocking permit

Stocking Fish in Wisconsin

Stocking into Waters of the State with Public Access

A DNR permit is required to stock or plant fish, including fish eggs, in waters of the state. Before a DNR fish manager can issue a stocking permit, the person requesting the permit must provide a copy of the most recent fish health certificate for the hatchery from which the fish will be stocked. The fish health certificate must be issued by a qualified inspector verifying that the fish health standards and requirements specified by DATCP are being met.

Generally, DNR fish managers like to have a fish survey before issuing a stocking permit. Public access lakes usually have a DNR fish survey. DNR fish managers consider the overall impact on the fishery when they review a stocking permit application. To apply, submit Form 9400-60, Fish Stocking Permit Application. For more information, go to:

www.dnr.state.wi.us/org/water/fhp/fish/aquaculture/stockper.htm

Stocking into Waters of the State without Public Access

Natural bodies of water that do not have public access are still considered waters of the state, and the same stocking requirements apply. DNR cannot perform a fish survey on bodies of water without public access, and it may be necessary to hire a private service. DNR fish managers must evaluate the overall impact on the fishery along with the wishes of the landowner or lake association.

Natural bodies of water on private property that don't meet the statutory requirements for freeze-out ponds cannot be legally operated as a fish farm. These deeper ponds can be stocked and used as a private fishing pond, but a DNR stocking permit is required. Also, all fishing activities must comply with all state fishing regulations, including seasons, size restrictions, bag limits, and possession of a fishing license.

Nuisance Animal and Plant Control Regulations in Wisconsin

Wild Animal Control

Some species of wild animals can be controlled by the owner or occupant of a fish farm operation without the need for any special permits, licenses, or prior authorization from the DNR. However, for the control of some species, such as muskrat and otter, certain criteria or conditions must first be met.

1. Beavers, raccoons, woodchucks, foxes, rabbits, coyotes, and squirrels

A fish hatchery owner or occupant, and any member of his or her family, may control these seven species of wild animals on their own property year-round without the need for any license or permit.

- Control methods include killing by shooting or trapping, and live trapping for relocation to more appropriate lands that are not public lands.
- The landowner is allowed to remove beaver dams.
- A landowner can set traps on a beaver dam. This privilege cannot be transferred to an agent or employee. The exception to this is when the landowner is a corporation or municipality. In this situation an employee or elected official may set traps on a beaver dam.
- A DNR permit is required to remove a beaver lodge, active or vacant.
- Hunting or shooting must comply with regular hunting rules such as legal shooting hours, restrictions on the use of artificial lights or shining, weapon types, and age restrictions. Check current small game hunting regulations for specific hunting and shooting regulations. Hunting is not allowed during the 24-hour period immediately preceding the gun deer season.
- Trapping must comply with regular trapping rules, and traps and snares must comply with legal designs and other placement restrictions. Check current trapping regulations for specific regulations.

With the exception of setting traps on a beaver dam, a fish hatchery owner or occupant may allow a non-family member to participate or assist with the removal of these species when these animals are causing a nuisance or damage. All participants are required to:

- Possess a valid hunting license if shooting the animals or a valid trapping license if trapping the animals.
- Possess written approval from the landowner that includes name, address and phone number of landowner; name, address and phone number of the person removing wild animals; property location and removal activities; authorized

period of removal; species of animals authorized for removal; signature of the landowner or lessee, and date.

2. Muskrat Nuisance Control

Musk rats are not an unprotected species and generally may not be trapped without a license or outside the open season. However if muskrats are causing damage to dikes, dams, shoreline, or roadways they can be controlled using the same methods and under the same conditions as outlined for the seven species listed above.

3. Otter Nuisance Control

Otters are a protected species and lethal control requires a written permit from the DNR. The following are some of the criteria DNR will evaluate in an application for destroying otters by shooting or trapping.

- What abatement methods are being used by the farmer?
- What is the extent of damage to the fish or ponds?
- Does the landowner allow other licensed trappers on their property?
- The entire otter carcass must be turned over to the DNR.

4. Unprotected Wild Animal Control

Opossums, skunks, weasels, house sparrows, and starlings are defined as unprotected wild animals, which means they may be hunted or trapped year-round and without bag limit restrictions. Persons taking unprotected animals must possess hunting or trapping licenses and comply with all method-of-taking requirements unless otherwise authorized by the department in writing. However, when these species are a nuisance or causing damage, the landowner, lessee, or occupants may, without a license, kill by shooting or trapping, or may live trap and relocate these species (except skunks) from those lands under their control to more appropriate lands that are not public lands. All skunks must be killed and may not be kept alive and relocated to other lands.

The landowner, lessee, or occupant may allow others to participate or assist with the removal of these unprotected species when these animals are causing a nuisance or damage. All participants are required to:

- Possess a valid hunting license if shooting the animals or a valid trapping license if trapping the animals.

Control of Protected Wild Birds

Some species of wild birds that may become a nuisance to fish farm owners may be controlled without the need for a written permit. However, the control of

most wild migratory birds requires a joint permit signed by both the U.S. Fish and Wildlife Service (FWS) and DNR.

1. Cowbirds, Crows, Grackles, and Red-Winged Blackbirds

Neither a federal nor state permit are required of any person to shoot or trap these species when they are committing or about to commit depredations upon agricultural crops, livestock, ornamental or shade trees, or when constituting a health hazard or other nuisance.

- Hunting or trapping licenses are not required.
- The hours for shooting during the open season for migratory birds is the same as those established for migratory game bird hunting. (See current migratory game bird hunting regulations for shooting hours.)

2. Cormorants, Herons, Waterfowl, Egrets, Ospreys, Pelicans, Ibises, Kingfishers, and Other Wild Birds

Farmers are allowed to harass or disturb these species (but not an endangered or threatened species) in such a way as to relieve a damage or nuisance situation as long as the bird is not harmed. Lethal control, involving either trapping or shooting birds, is illegal without a permit from the FWS and the DNR. Common abatement practices are to install netting, wire grids, and fencing for long-term protection. For short-term protection, farmers should try using noise-making devices, such as propane cannons and cracker shells, as well as visual tools, like “eye-spot” balloons, remote-control boats and airplanes, scarecrows, lights, dogs, and harassment patrols.

If barriers and scaring techniques fail to reduce fish losses, as a last resort the FWS and DNR may issue a depredation permit to remove a limited number of birds from a specific farm. The issuance of these permits is rigidly controlled because most fish-eating birds are protected by the Migratory Bird Treaty Act.

To inquire about a permit to use lethal control, a farmer should first contact the Wildlife Services staff at a U. S. Department of Agriculture regional office in Horicon or Rhinelander. Wildlife Services staff will investigate the situation and decide if a depredation permit to remove a limited number of birds is justified. If it is necessary, they will help the farmer apply for the permit to the FWS, which is an agency of the Department of Interior. If the FWS issues a depredation permit, it is then reviewed by the DNR. If the DNR concurs with the issuance of the permit, the DNR co-signs the permit.

Aquatic Plant and Algae Control

Wisconsin statutes specifically exempt manual, mechanical, and chemical methods for managing rooted aquatic plants and algae on registered fish farms. If your facility is registered with DATCP as a fish farm, you are exempt from all

permit requirements when engaged in aquatic plant management in the course of operating a fish farm.

If your facility is not a registered fish farm, you must obtain a valid aquatic plant management permit from DNR for chemical treatment of aquatic plants, under NR 107, Wisconsin Administrative Code. The chemicals must be labeled for use in surface water. Manual or mechanical removal of aquatic plants is regulated under NR 109, Wisconsin Administrative Code. Under NR 109, no permit is needed for manual removal or using a mechanical device to control aquatic plants, if the body of water is 10 acres or less and is entirely confined on the property of one person (with that property owner's permission). A NR 109 permit is required if you do not meet these criteria.

Permit applications and more information about chemical, manual, or mechanical control of aquatic vegetation can be obtained from your local DNR Aquatic Plant Management Coordinator.

For a list of local Aquatic Plant Management Coordinators by county go to the DNR Web site: www.dnr.state.wi.us/org/water/wm/dsfm/shore/county.htm.

Pond Construction and Water-Related Activities Regulation in Wisconsin

Pond Construction

In Wisconsin, water-related activities such as building ponds, grading along streams, placing structures in streams, and dredging are regulated by a statute called Chapter 30. Permits required under this statute are often called Chapter 30 permits. In 2004, the statute was revised by the Wisconsin Legislature to streamline the regulatory process for obtaining a permit. The administrative codes now in effect exempt some activities from Chapter 30 permits. Statewide general permits have also been developed to cover some types of activities.

For some projects that have minor environmental impact, such as riprap repair, hand dredging, or culvert replacement, the owner should use an exemption check sheet, which will list all the criteria to determine if the project qualifies for a Chapter 30 exemption. If the check sheet review is not obvious, you can get an official determination from DNR about your proposed project by submitting a Chapter 30 Exemption Determination Request on Form 3500-107.

For the projects discussed below that might require a Chapter 30 permit, the owner should check to see if a general permit is available for the activity. Projects that meet all the criteria for a general permit can be authorized by submitting Form 3500-108, Waterway General Permit Application, to the DNR at least 35 days prior to starting construction. To review the rules and the general permits and to download copies of the application forms, go to the DNR Web site at www.dnr.state.wi.us/org/water/fhp/fish/aquaculture/envperm.htm.

1. Constructing and Enlarging Ponds and Grading

These are the types of construction activities that will require a DNR Chapter 30 permit.

- Unconnected ponds within 500 feet of a navigable waterway. A stream is navigable if it has a bed and banks and you can float the stream in a canoe or other small craft at some time of the year, even if only during spring floods. An unconnected pond is defined as a waterway that does not have an open or closed outlet that discharges to another waterbody.
- Ponds with open or closed outlets to public navigable waters, even if the pond is greater than 500 feet from the waterway. Connected is defined as any waterway joined to an existing public waterway by any means that tends to confine and direct flow into the existing navigable waterway and has a regular discharge via the conduit.
- Ponds connected by an open navigable channel to an existing public navigable waterway, or any enlargement of any public navigable waterway. Enlargement or connection means the direct physical joining of a waterway below the ordinary high water mark of an existing public waterway by a channel having bed and banks.
- Grading in excess of 10,000 square feet on the bank of a public navigable waterway.

2. Construction in wetlands

Construction in an isolated wetland is regulated by DNR, but construction in wetlands adjacent to a navigable stream is regulated by both the U.S. Army Corps of Engineers and DNR. If the proposed construction has any impacts to wetlands, a Water Quality Certification (WQC) may be required. The project will have to meet the State Water Quality Standards for Wetlands as specified in NR 103, Wis. Adm. Code. WQC is required to validate an Army Corps of Engineers 404 wetland permit for federal wetlands. To apply for a WQC, submit Form 3500-53N, Application for Wetland Water Quality Certification.

DNR occasionally approves construction of wetland ponds, if the landowner can show that there are no other alternatives and that the functions of the wetland will not be harmed. Pond construction in a high-quality wetland will not be permitted. In some cases, landowners may not be aware that they have wetlands on their property, especially if the area has been cultivated. Although the site may look like a field, if it has poorly drained soils and water close enough to the surface to support wetland plants; it is probably a wetland. Wetland maps for each county are available from county zoning administrators.

Using an Existing Pond

New fish farmers often have an existing pond on their property that they'd like to use for fish rearing. However, if an existing pond meets the legal definition of a "natural body of water," it may not be legal to use it as a fish farm unless it can meet several important requirements. A "natural body of water" is a spring,

stream, pond, lake, or wetland that was historically present in a natural state, even though it may have been physically altered over time. A DNR permit is required for any registered fish farm to use a natural body of water for its aquaculture operation. A body of water that was licensed by DNR on January 1, 1998, as a private fish hatchery was eligible for a grandfathered permit, but new natural waterbody permits can only be issued for shallow ponds (generally less than 5 feet deep) that freeze out 2 out of 5 years. Also, you must lease or own all the land around the pond so that no public access is provided.

Examples of a natural body of water include:

- Waters that are, or existed as, naturally occurring springs, ponds, or streams;
- Ponds constructed in natural springs, wetlands, streams, ponds, or lakes;
- Ponds created by damming a stream.

To apply for a natural waterbody permit, submit Form 3600-227, Fish Farm Application For Use of Natural Body of Water, along with the necessary attachments to your local Fish Farm Environmental Permits Coordinator.

Dam Construction

Although the damming of a stream to create an aquaculture pond is not allowed, it may be acceptable to construct a dam in order to create a pond from which you withdraw water for your fish farm. Permits are needed to construct dams or impoundment on waterways in accordance with Chapter 31 of Wisconsin statutes. Dams on navigable streams require extensive review to evaluate impacts to fish and aquatic life as well as neighbors upstream and downstream, and a public hearing is held on each application. Dams proposed to be constructed on non-navigable streams must also have the plans approved by DNR, but the design criteria are not as stringent.

Wisconsin Department of Agriculture, Trade and Consumer Protection rules for Aquaculture

ATCP 10.025 Reportable diseases; fish.

(1) REPORT REQUIRED.

A person who diagnoses or finds evidence of any of the following diseases in this state shall report that diagnosis or finding to the department, in writing or by telefax, within 10 days after making the diagnosis or finding:

- (a) Any aquatic animal disease that is foreign or exotic to Wisconsin.
- (b) Channel catfish virus (CCV).
- (c) Enteric septicemia of catfish (ESC).
- (d) Infectious hematopoietic necrosis virus (IHN).
- (e) White sturgeon iridovirus (WSI).
- (f) Mycobacteriosis infection.
- (g) Proliferative kidney disease (PKD).
- (h) *Streptococcus iniae*.
- (i) Viral hemorrhagic septicemia (VHS).
- (j) Whirling disease (*Myxobolus cerebralis*, or WD).

(2) EXEMPTION.

Subsection (1) does not require a person to report a diagnosis or finding made by the department or the Wisconsin Department of Health and Family Services.

(3) NOTICE TO THE DEPARTMENT OF NATURAL RESOURCES.

If the department determines that a disease reported under sub. (1) may present a threat to fish in the waters of the state, the department shall notify the Department of Natural Resources of the report contents.

ATCP 10.73 Fish farms.

(1) DEFINITIONS.

In this section:

- (a) “Certified fish inspector” means any of the following:
 1. An individual who is currently certified by the American Fisheries Society as a fish health inspector or fish pathologist.
 2. An individual whom a state authorizes and the department approves to certify, on behalf of that state, the health of fish in that state.
- (b) “Certified veterinarian” means a Wisconsin certified veterinarian whom the department has trained to perform fish disease control and eradication functions except that, for actions taken under this section outside this state, “certified veterinarian” means an accredited veterinarian.
- (c) “Commingled” means kept or brought in contact with other fish or fish eggs in any environment which permits direct contact between fish or use of the same water system.

(d) “Fish farm” means a facility at which a person hatches fish eggs or holds live fish.

(e) “Food processing plant” means a facility licensed under s. 97.29, Stats.

(f) “Individual” means a natural person.

(g) “Operator” means a person who owns or controls a fish farm. “Operator” includes the operator’s employees and agents.

(h) “Ornamental fish” means goldfish, koi, tropical freshwater fish that cannot survive in temperatures below 38°F, saltwater fish and other fish which the department designates in writing.

Note: You may obtain a current list of fish designated as “ornamental fish” by contacting the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(i) “Person” means an individual, corporation, partnership, cooperative association, limited liability company, trust, the state of Wisconsin or its agencies, or other organization or entity.

(j) “Retail food establishment” means a facility licensed under s. 97.30, Stats.

(k) “Restaurant” means a facility licensed under s. 254.64, Stats.

(l) “Salmonid” means fish or fish eggs of the family that includes trout, salmon, grayling, char, Dolly Vardon, whitefish, cisco and inconnu.

(m) “Self-contained fish rearing facility” has the meaning given in s. 29.001 (76), Stats.

(n) “Untreated water” means water that has not been rendered free of pathogens by a method approved by the department.

(o) “Waters of the state” has the meaning given in s. 281.01 (18), Stats.

(2) REGISTRATION CERTIFICATE REQUIRED.

Except as provided in sub. (3), a person operating a fish farm for any of the following purposes shall obtain a registration certificate for that fish farm:

(a) Hatching fish eggs or holding live fish for any of the following purposes:

1. Sale or distribution.
2. Introduction into the waters of the state.
3. Fishing.
4. Use as bait or fertilizer.
5. Use as human food or animal feed.
6. Education, demonstration or research.

(b) Holding live fish or fish eggs owned by another person.

Note: A Wisconsin Department of Natural Resources (DNR) fish stocking permit is not needed to stock fish into a fish farm registered under sub. (2). However, a DNR stocking permit is needed to stock fish into the waters of the state. (See s. 29.736, Stats.)

A DNR sport fishing license is not required to fish within a registered fish farm. Persons fishing at a registered fish farm do not need to comply with season, size or bag limits. (See s. 29.001 (27), Stats.)

Toxicants required for fish farming operations may be used in self-contained fish rearing facilities if there is no discharge from the facility, or if the discharge of the chemical is allowed under a Wisconsin Pollutant Discharge Elimination System (WPDES) permit. Otherwise, a DNR aquatic pesticide use permit is required. (See ss. 29.088 (2) (g), 29.601 (5) (b) and 283.31, Stats.) Pesticide applications must comply with ch. ATCP 29, Wis. Adm. Code, administered by the Department of Agriculture, Trade and Consumer Protection. There may be other federal, state, or local regulations pertaining to the use of these toxicants.

(3) EXEMPTIONS.

A person may do any of the following without a registration certificate under sub. (2):

(a) Hold, rear, sell or distribute live ornamental fish, or hatch the eggs of ornamental fish, unless the ornamental fish or fish eggs are commingled with non-ornamental fish or fish eggs or are reared for bait, human food or animal feed.

(b) Hold live bait fish under a bait dealer license issued by the state of Wisconsin Department of Natural Resources under s. 29.509, Stats.

(c) Hold or rear live fish, or hatch fish eggs, in a fully enclosed building solely for purposes of display or research within that building, provided that no untreated water used to hold those fish or fish eggs is discharged to waters of the state.

(d) Exhibit live fish in a public forum for not more than 15 days in a calendar year, or for a longer period of time which the department authorizes in writing for a specific exhibit.

(e) Hold live fish or fish eggs for not more than 30 days at a food processing plant, retail food establishment or restaurant pending slaughter or sale to consumers at that facility, provided that the facility does not discharge to waters of the state any untreated water used to hold or process those fish or fish eggs.

(f) Transport live fish or fish eggs to or from a fish farm.

(4) TYPE 1 OR TYPE 2 REGISTRATION CERTIFICATE.

(a) Except as provided in par. (b), a person required to hold a fish farm registration certificate under sub. (2) may hold either a type 1 or type 2 registration certificate.

(b) A person may not sell or distribute live fish or fish eggs from a fish farm without a type 2 registration certificate, except that a person holding a type 1 registration certificate may do any of the following:

1. Allow fishing at the fish farm, including public fishing for a fee.

2. Sell or distribute live fish or fish eggs to a food processing plant, retail food establishment or restaurant at which the fish or fish eggs are held for not more than 30 days pending slaughter or sale to consumers at that facility, provided that the facility does not discharge to waters of the state any untreated water used to hold or process those fish or fish eggs.

3. Move live fish between type 1 fish farms which that person operates in this state.

Note: A person holding a type 1 registration certificate may, at any time during the registration year, convert that certificate to a type 2 certificate by paying the additional fee under sub. (8) and complying with health certification requirements under sub. (14).

(5) ANNUAL EXPIRATION DATE.

A fish farm registration certificate under sub. (2) expires on December 31 of the calendar year for which it is issued.

(6) PERSONS OPERATING 2 OR MORE FISH FARMS.

A person who operates 2 or more fish farms shall obtain a separate registration certificate under sub. (2) for each fish farm. A person may obtain annual registration certificates for 2 or more fish farms by filing a single annual application under sub. (7) and paying a single annual fee under sub. (8). There is no additional charge for additional fish farms. A registration certificate is not transferable between persons or locations.

Note: A person registering 2 or more fish farms may choose to register those fish farms as type 1 or type 2 fish farms. The applicant submits only one annual application and pays only one annual fish farm registration fee. There is no additional charge to register additional fish farms. If any of the fish farms is registered as a type 2 fish farm, the applicant must pay the type 2 registration fee.

(7) APPLYING FOR A REGISTRATION CERTIFICATE.

To obtain or renew a fish farm registration certificate under sub. (2), a fish farm operator shall file an application with the department. The operator shall file an application on a form provided by the department. An operator may, by filing a single application form, obtain registration certificates for 2 or more fish farms. The application shall include all of the following:

(a) The name, address and telephone number of the fish farm operator.

(b) The location of each fish farm for which the operator seeks a registration certificate. The location shall include the county, township, section number and fire number of the fish farm.

(c) For each fish farm under par. (b), a statement indicating whether the operator seeks a type 1 or type 2 registration certificate.

- (d) The fee required under sub. (8).
- (e) The name, address and telephone number of the individual responsible for administering each of the fish farms under par. (b) on behalf of the operator, if the individual administering that fish farm is not the operator.
- (f) The species of fish hatched or kept at each fish farm under par. (b).
- (g) A description of each fish farm under par. (b), including fish farm facilities and activities.
- (h) A copy of each health certificate required under sub. (13) for a type 1 fish farm or under sub. (14) for a type 2 fish farm. If an operator is registering a fish farm for the first time, the department may issue a registration certificate before the operator files a health certificate, provided that the operator obtains and files the required health certificate within 30 days after the department issues the registration certificate or within 30 days after the operator stocks fish at the fish farm.
- (i) Other relevant information required by the department.

Note: You may obtain a registration form by contacting the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

A fish farm operator may also need certain permits from the Wisconsin Department of Natural Resources (DNR). Contact DNR to find out about DNR permit requirements.

(8) REGISTRATION FEES.

- (a) Except as provided in par. (b), an operator shall pay the following annual fee to obtain registration certificates for one or more fish farms:
 - 1. A total fee of \$25 if the fish farms are all type 1 fish farms.
 - 2. A total fee of \$50 if any of the fish farms is a type 2 fish farm.
- (b) The following persons are exempt from registration fees under this subsection:
 - 1. A bona fide scientific research organization that is operating a fish farm solely for the purpose of scientific research.
 - 2. A primary or secondary school.
 - 3. The state of Wisconsin and its agencies.
- (c) A fish farm operator shall pay the full annual registration fee for a fish farm registered for less than a full calendar year.
- (d) An applicant for an annual fish farm registration certificate under sub. (2) shall pay, in addition to the annual registration fee prescribed by this subsection,

a surcharge equal to the amount of that fee if the department determines that, within 365 days prior to submitting an application, the applicant operated a fish farm without a registration certificate in violation of sub. (2) or (4) (b). Payment of the surcharge does not relieve the applicant of any other civil or criminal penalty or liability that may result from the violation, nor does it constitute evidence of a violation.

Note: Under s. 93.21 (5) (b), Stats., a person who files a late application for renewal of a registration certificate must pay, in addition to the fee prescribed under sub. (8), an additional fee equal to 20 percent of that registration fee.

(9) ACTION ON REGISTRATION APPLICATION.

The department shall grant or deny a registration application within 30 days after the applicant files a complete application under sub. (7).

(10) DENYING, SUSPENDING OR REVOKING A REGISTRATION CERTIFICATE.

The department may deny, suspend or revoke a fish farm registration certificate for cause, including any of the following:

- (a) Filing an incomplete or fraudulent application, or misrepresenting any information on an application.
- (b) Violating applicable provisions of ch. 95, Stats., this chapter, or ch. ATCP 11.
- (c) Violating the terms of the registration certificate.
- (d) Preventing a department employee from performing his or her official duties, or interfering with the lawful performance of his or her duties.
- (e) Physically assaulting a department employee while the employee is performing his or her official duties.
- (f) Refusing or failing, without just cause, to produce records under sub. (11) or respond to a department subpoena.
- (g) Paying a registration fee with a worthless check.

Note: The denial, suspension or revocation of a registration certificate is subject to a right of hearing under ch. 227, Stats., and ch. ATCP 1, Wis. Adm. Code. The department will not deny registration to a new owner of a fish farm merely because ownership has changed.

(11) RECORDKEEPING.

(a) A fish farm operator shall keep all of the following records related to fish or fish eggs which the operator ships from or receives at the fish farm:

1. The name, address, and fish farm registration number, if any, of the person from whom the operator received, or to whom the operator delivered fish or fish eggs.
2. The date on which the operator received or delivered the fish or fish eggs.
3. The location at which the operator received or delivered the fish or fish eggs.
4. The size or class, quantity and species of fish or fish eggs received or delivered.

(b) An operator required to keep records under par. (a) shall retain those records for at least 5 years and shall make them available to the department, upon request, for inspection and copying.

(12) FISH SOURCE.

(a) No person selling or distributing fish or fish eggs may misrepresent, directly or by implication, the source or disposition of those fish or fish eggs.

(b) A person transporting fish or fish eggs from a fish farm shall have documentary evidence showing that the person obtained those fish from that fish farm. Evidence may include a bill of sale, bill of lading, import permit, health certificate, certificate of veterinary inspection or other document which identifies the fish farm.

(13) TYPE 1 FISH FARM; ANNUAL HEALTH CERTIFICATE.

(a) No person may obtain a type 1 fish farm registration certificate for any calendar year beginning after December 31, 2001 unless one of the following applies:

1. A certified veterinarian or certified fish inspector has issued a health certificate for that fish farm not earlier than January 1 of the preceding calendar year.

2. A certified veterinarian or certified fish inspector has issued a health certificate, not earlier than January 1 of the preceding calendar year, for each fish farm from which the fish farm operator received fish or fish eggs in the preceding calendar year.

(b) Health certificates issued under par. (a) shall comply with the same requirements that apply to health certificates issued for type 2 fish farms under sub. (14).

(c) A fish farm operator shall include copies of all health certificates required under par. (a) with the operator's application for an annual fish farm registration certificate under sub. (7).

(14) TYPE 2 FISH FARM; ANNUAL HEALTH CERTIFICATE.

(a) No person may obtain a type 2 fish farm registration certificate for any calendar year beginning after December 31, 2001 unless a certified veterinarian or certified fish inspector issues a health certificate for that fish farm not earlier than January 1 of the preceding calendar year. The certified veterinarian or certified fish inspector shall issue the health certificate on a form provided by the department, based on a personal inspection of the fish farm. The certified veterinarian or certified fish inspector shall use inspection, sampling and diagnostic methods specified by the department on the certification form.

Note: To obtain a health certification form, contact the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(b) A health certificate under par. (a) shall certify all of the following:

1. That fish at the fish farm are free of visible signs of infectious or contagious disease.

2. That salmonids at the fish farm are free of whirling disease (*Myxobolus cerebralis*, or WD), if any salmonids are hatched or kept at the fish farm.

3. That fish at the fish farm are free of other diseases, if any, which the department specifies on the certification form.

(c) A certified veterinarian or certified fish inspector who issues a health certificate under this subsection shall file the original certificate with the department, and shall provide at least 2 copies to the fish farm operator. A fish farm operator shall include a copy of the certificate with the operator's application for an annual fish farm registration certificate under sub. (7).

Note: A certification form which specifies disease inspection, sampling and diagnostic procedures under sub. (14) (a), or additional disease certification requirements under sub. (14) (b) 3., constitutes an order under s. 93.07 (10), Stats., which is reviewable under ch. 227, Stats., and ch. ATCP 1 unless the department has adopted those requirements by rule. If a health certification does not comply with instructions on the certification form, the certification is invalid.

ATCP 11.58 Fish imports.

(1) DEFINITIONS.

In this section:

(a) "Certified fish inspector" means any of the following:

1. An individual who is currently certified by the American Fisheries Society as a fish health inspector or fish pathologist.

2. An individual whom a state authorizes and the department approves to certify, on behalf of that state, the health of fish in that state.

(b) "Commingled" means kept or brought in contact with other fish or fish eggs in any environment which permits direct contact between fish or use of the same water system.

(c) "Fish farm" means a facility at which a person hatches fish eggs or holds live fish.

(d) "Food processing plant" means a facility licensed under s. 97.29, Stats.

(e) "Individual" means a natural person.

(f) "Operator" means a person who owns or controls a fish farm. "Operator" includes the operator's employees and agents.

(g) “Ornamental fish” means goldfish, koi, tropical freshwater fish that cannot survive in temperatures below 38°F, saltwater fish and other fish which the department designates in writing.

Note: You may obtain a current list of fish designated as “ornamental fish” by contacting the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(h) “Person” means an individual, corporation, partnership, cooperative association, limited liability company, trust, the state of Wisconsin or its agencies, or other organization or entity.

(i) “Retail food establishment” means a facility licensed under s. 97.30, Stats.

(j) “Restaurant” means a facility licensed under s. 254.64, Stats.

(k) “Salmonid” means fish or fish eggs of the family that includes trout, salmon, grayling, char, Dolly Vardon, whitefish, cisco and inconnu.

(l) “Untreated water” means water that has not been rendered free of pathogens by a method approved by the department.

(m) “Waters of the state” has the meaning given in s. 281.01 (18), Stats.

(n) “Wild source” means waters in this state that are not registered as fish farms, or waters outside this state that are not fish farms.

(2) ANNUAL IMPORT PERMIT REQUIRED.

Except as provided in sub. (3), no person may import live fish or fish eggs into this state for any of the following purposes except under an annual written import permit from the department:

(a) Introducing the live fish or fish eggs into waters of the state.

(b) Using the live fish or fish eggs as bait.

(c) Holding the live fish or hatching the fish eggs at a fish farm for which a registration certificate is required under s. ATCP 10.73 (2).

(d) Selling or distributing the live fish or fish eggs for any of the purposes under pars. (a) to (c).

Note: A person importing any of the following must also obtain an importation permit from the state of Wisconsin Department of Natural Resources (DNR):

Live fish or fish eggs of species that are not native to Wisconsin. (See s. 29.735 (1), Stats.)

Live rough fish or rough fish eggs, except goldfish, dace and suckers. (See s. 29.407 (4), Stats.)

An application for an import permit under this section also serves as an application for a DNR import permit. The department will forward the permit application to DNR if DNR permit requirements apply.

Under s. 29.736, Stats., no person may use imported fish or fish eggs to stock waters of the state without a stocking permit from DNR (unless the stocking is subject to an exemption under s. 29.736, Stats.). An import permit application under this section does not serve as an application for a DNR stocking permit.

(3) EXEMPTIONS.

No permit is required under sub. (2) to import any of the following:

(a) Live ornamental fish or the eggs of ornamental fish, unless the ornamental fish or fish eggs are commingled with non-ornamental fish or fish eggs, or are reared for bait, human food or animal feed.

(b) Live fish or fish eggs that will be held, for the remainder of their lives, in fully enclosed buildings solely for purposes of display or research, provided that no untreated water used to hold those fish or fish eggs is discharged to waters of the state.

(c) Live fish imported directly to a food processing plant, retail food establishment or restaurant where they will be held for not more than 30 days pending slaughter or sale to consumers at that facility, provided that the facility does not discharge to waters of the state any untreated water used to hold or process those fish or fish eggs.

(d) Live fish or fish eggs imported and held for not more than 30 days in fully enclosed buildings pending shipment out of this state, provided that no untreated water used to hold those fish or fish eggs is discharged to waters of the state.

(e) Live fish or fish eggs that are directly imported by the Wisconsin Department of Natural Resources.

(4) ISSUING AN ANNUAL IMPORT PERMIT.

The department may issue an import permit under sub. (2) for all or part of a calendar year, based on an application under sub. (9). A permit holder may, at any time, apply under sub. (9) for an amendment to an existing permit.

(5) COPY MUST ACCOMPANY IMPORT SHIPMENT.

Every import shipment under sub. (2) shall be accompanied by a copy of the import permit which authorizes that shipment.

(6) IMPORT RECIPIENTS.

A person holding an import permit under sub. (2) may import live fish or fish eggs to the following persons, and no others:

(a) A person holding a current fish farm registration certificate, under s. ATCP 10.73, which authorizes that person to hold live fish or fish eggs of the type imported.

(b) The state of Wisconsin Department of Natural Resources.

(c) A person holding a current fish stocking permit, under s. 29.736, Stats., which authorizes that person to stock live fish or fish eggs of the type imported.

(d) A person holding a current bait dealer license under s. 29.509, Stats., which authorizes that person to hold live fish or fish eggs of the type imported.

(e) Other persons identified by the department in the permit.

(7) UNAUTHORIZED IMPORTS.

No person holding an import permit under sub. (2) may violate the terms of the permit or exceed the authorization granted in the permit. A permit is not transferable between importers.

(8) IMPORT PERMIT; CONTENTS.

An import permit under sub. (2) shall include all of the following:

(a) The expiration date of the import permit. An import permit expires on December 31 of the year for which it is issued, unless the department specifies an earlier expiration date.

(b) The name, address and telephone number of the permit holder.

(c) Each species of fish or fish eggs that the permit holder may import under the permit.

(d) The size or class of fish of each species, and the quantity of fish or fish eggs of each species, that the permit holder may import under the permit.

(e) The sources from which the importer may import live fish or fish eggs under the permit. The permit may incorporate, by reference, sources identified in the permit application under sub. (9).

(f) The type of import recipient under sub. (6) to which the importer may import live fish or fish eggs under the permit.

(9) APPLYING FOR A PERMIT.

A person seeking an import permit under sub. (2) shall apply on a form provided by the department. There is no fee. A permit application shall include all of the following:

(a) The applicant's name, address and telephone number.

(b) Each species of fish or fish eggs that the applicant proposes to import.

(c) The size or class of fish of each species, and quantity of fish or fish eggs of each species, that the applicant proposes to import.

(d) Every wild source from which the applicant proposes to capture and import fish or fish eggs.

(e) The name, address and telephone number of every fish farm from which the applicant proposes to import fish or fish eggs, and a copy of any health certificate issued for that fish farm under sub. (16).

(f) The type of import recipient under sub. (6) that the applicant proposes to import fish or fish eggs to.

Note: You may obtain an application form by contacting the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(10) ACTION ON PERMIT APPLICATION.

The department shall grant or deny a permit application under sub. (9) within 30 days after the department receives a complete application.

Note: The department may impose conditions on an import permit, pursuant to s. 93.06 (8), Stats.

(11) DENYING, SUSPENDING OR REVOKING AN IMPORT PERMIT.

The department may deny, suspend or revoke an import permit under sub. (2) for cause, including any of the following:

(a) Filing an incomplete or fraudulent permit application, or misrepresenting any information on a permit application.

(b) Violating applicable provisions of ch. 95, Stats., this chapter or ch. ATCP 10.

(c) Violating the terms of the import permit, or exceeding the import authorization granted by the permit.

(d) Preventing a department employee from performing his or her official duties, or interfering with the lawful performance of his or her duties.

(e) Physically assaulting a department employee while the employee is performing his or her official duties.

(f) Refusing or failing, without just cause, to produce records under sub. (12) or respond to a department subpoena.

Note: The denial, suspension or revocation of an import permit is subject to a right of hearing under ch. 227, Stats., and ch. ATCP 1, Wis. Adm. Code.

(12) IMPORT RECORDS.

(a) A person, including the Wisconsin Department of Natural Resources, that imports fish or fish eggs under sub. (2) shall keep all of the following records related to each import shipment:

1. The date of the import shipment.

2. The wild source, if any, from which the importer obtained the imported fish or fish eggs.

3. The name, address and telephone number of the fish farm from which the importer obtained the imported fish or fish eggs, if the importer obtained them from a fish farm.

4. The name, address and telephone number of the person receiving the import shipment if that person is not the importer. The importer shall also record the recipient's fish farm registration number under s. ATCP 10.73, stocking permit number under s. 29.736, Stats., or bait dealer license number under s. 29.509, Stats., if any.

Note: See sub. (6).

5. The location at which the import shipment was received in this state.

6. The size or class, quantity and species of fish or fish eggs included in the import shipment.

(b) A person required to keep records under par. (a) shall retain those records for at least 5 years and shall make them available to the department, upon request, for inspection and copying.

Note: An import permit holder must keep and provide records under sub. (12), regardless of whether the importer is located in this state or another state. The department may deny, suspend or revoke an import permit under sub. (11) if the importer fails to keep records, or fails to provide them to the department upon request.

(13) IMPORTING DISEASED FISH.

No person may import any live fish or fish eggs into this state if that person knows, or has reason to know, that those fish or fish eggs are infected or show clinical signs of any reportable disease under s. ATCP 10.025.

(14) HEALTH CERTIFICATE REQUIRED.

No person may import any shipment of live fish or fish eggs into this state unless one of the following applies:

(a) The import shipment is accompanied by a health certificate issued for that shipment under sub. (15).

(b) The import shipment originates from a fish farm and all of the following apply:

1. The import shipment is labeled with the name and address of that fish farm.
2. No fish or fish eggs in the import shipment were ever collected from a wild source.
3. An accredited veterinarian or certified fish inspector has issued an annual health certificate for that fish farm under sub. (16), and has filed a copy of that certificate with the department.

4. The importer has filed a copy of the annual fish farm health certificate with the importer's permit application under sub. (9) or, if the state of Wisconsin Department of Natural Resources is the importer, the Department of Natural Resources has filed a copy of the annual fish farm health certificate with the department before importing fish to this state in any calendar year.

(c) The import shipment consists solely of any of the following:

1. Live ornamental fish, or the eggs of ornamental fish, unless the ornamental fish or fish eggs are commingled with non-ornamental fish or fish eggs, or are reared for bait, human food or animal feed.

2. Live fish or fish eggs that will be held, for the remainder of their lives, in fully enclosed buildings solely for purposes of display or research, provided that no untreated water used to hold those fish or fish eggs is discharged to waters of the state.

3. Live fish imported directly to a food processing plant, retail food establishment or restaurant where they will be held for not more than 30 days pending slaughter or sale to consumers at that facility, provided that the facility does not discharge to waters of the state any untreated water used to hold or process those fish or fish eggs.

4. Live fish or fish eggs imported and held for not more than 30 days in fully enclosed buildings pending shipment out of this state, provided that no untreated water used to hold those fish or fish eggs is discharged to waters of the state.

(15) HEALTH CERTIFICATE; INDIVIDUAL SHIPMENT.

The following requirements apply to a health certificate under sub. (14) (a):

(a) An accredited veterinarian or certified fish inspector shall issue the health certificate in the state of origin, on a form provided by the department, based on a personal inspection of the import shipment. The accredited veterinarian or certified fish inspector shall use inspection, sampling and diagnostic methods specified by the department on the certification form.

Note: To obtain a health certification form, contact the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(b) The health certificate under par. (a) shall certify that the import shipment is free of all the following:

1. Visible signs of infectious or contagious disease.
2. Infectious hematopoietic necrosis (IHN) and viral hemorrhagic septicemia (VHS), if the import shipment includes salmonids. If the import shipment includes fish of the salmonid family, the health certificate shall also certify that those fish are free of whirling disease (*Myxobolus cerebralis*, or WD).
3. White sturgeon iridovirus (WSI) if the import shipment includes sturgeon.
4. Other diseases, if any, which the department specifies on the certification form.

(c) The accredited veterinarian or certified fish inspector who issues the health certificate shall file the original certificate with the department, and shall provide at least 2 copies to the importer.

Note: A certification form which specifies disease inspection, sampling and diagnostic procedures under sub. (15) (a), or additional disease certification requirements under sub.(15) (b) 4., constitutes an order under s. 93.07 (10), Stats.,

which is reviewable under ch. 227, Stats., and ch. ATCP 1 unless the department adopts those requirements by rule. If a health certification does not comply with instructions on the certification form, the certification is invalid.

**(16) FISH IMPORTED FROM FISH FARM;
ANNUAL HEALTH CERTIFICATE.**

The following requirements apply to an annual fish farm health certificate under sub. (14) (b) 3.:

(a) An accredited veterinarian or certified fish inspector shall issue the annual health certificate in the state of origin, on a form provided by the department, based on a personal inspection of the fish farm. The accredited veterinarian or certified fish inspector shall use inspection, sampling and diagnostic methods specified by the department on the certification form.

Note: To obtain a health certification form, contact the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(b) The annual health certificate shall certify that the fish farm is free of all the following:

1. Visible signs of infectious or contagious disease.
2. Infectious hematopoietic necrosis (IHN), viral hemorrhagic septicemia (VHS) and whirling disease (*Myxobolus cerebralis*, or WD), if the health certificate is used for imports of salmonids.
3. White sturgeon iridovirus (WSI) if the health certificate is used for imports of sturgeon.
4. Other diseases, if any, which the department specifies on the certification form.

(c) The accredited veterinarian or certified fish inspector who issues the annual health certificate shall file the original certificate with the department, and shall provide at least 2 copies to the fish farm operator.

Note: A certification form which specifies disease inspection, sampling and diagnostic procedures under sub. (16) (a), or additional disease certification requirements under sub.(16) (b) 4., constitutes an order under s. 93.07 (10), Stats., which is reviewable under ch. 227, Stats., and ch. ATCP 1 unless the department adopts those requirements by rule. If a health certification does not comply with instructions on the certification form, the certification is invalid.

ATCP 11.59 Health standards for fish introduced into waters of the state.

(1) DEFINITIONS.

In this section:

(a) “Certified fish inspector” means any of the following:

1. An individual who is currently certified by the American Fisheries Society as a fish health inspector or fish pathologist.

2. An individual whom a state authorizes and the department approves to certify, on behalf of that state, the health of fish in that state.

(b) “Certified veterinarian” means one of the following:

1. For actions taken in this state, a Wisconsin certified veterinarian whom the department has trained to perform disease eradication and control functions related to fish.

2. For actions taken outside this state, an accredited veterinarian.

(c) “Fish farm” means a facility at which a person hatches fish eggs or holds live fish.

(d) “Individual” means a natural person.

(e) “Person” means an individual, corporation, partnership, cooperative association, limited liability company, trust, the state of Wisconsin or its agencies, or other organization or entity.

(f) “Salmonid” means fish or fish eggs of the family that includes trout, salmon, grayling, char, Dolly Vardon, whitefish, cisco and inconnu.

(g) “Waters of the state” has the meaning given in s. 29.736 (1) (c), Stats.

(2) HEALTH CERTIFICATE REQUIRED.

(a) No person may introduce live salmonids into waters of the state after June 1, 1999, and no person may introduce other live fish or fish eggs into waters of the state after December 31, 2001, unless a certified veterinarian or certified fish inspector does one of the following:

1. Issues a health certificate for those fish or fish eggs.

2. Issues a health certificate, not earlier than January 1 of the calendar year preceding the year in which the fish are introduced into waters of the state, for the fish farm from which those fish or fish eggs originate.

Note: See fish stocking regulations under s. 29.736, Stats. In addition to fish stocked from private fish farms, this subsection also pertains to fish stocked by the Wisconsin Department of Natural Resources.

(b) A fish health certificate under par. (a) shall certify that the fish or fish eggs, or the fish farm from which they originate, are free of all the following:

1. Visible signs of infectious or contagious disease.

2. Whirling disease (*Myxobolus cerebralis*, or WD), if the health certificate is used for introducing fish of the salmonid family.

3. Other diseases, if any, which the department specifies on the certification form.

(3) ISSUING A HEALTH CERTIFICATE.

(a) A certified veterinarian or certified fish inspector shall issue a health certificate under sub. (2) on a form provided by the department, based on a personal inspection of the fish or fish farm. The certified veterinarian or certified fish inspector shall use inspection, sampling and diagnostic methods specified by the department on the certification form.

Note: To obtain a health certification form, contact the department at the following address:

Wisconsin Department of Agriculture, Trade and Consumer Protection
Division of Animal Health
P.O. Box 8911
Madison, WI 53708-8911
Phone: (608) 224-4872

(b) A certified veterinarian or certified fish inspector who issues a health certificate under sub. (2) shall file the original certificate with the department, and shall provide at least 2 copies to the person introducing the fish or fish eggs into waters of the state.

Note: A certification form which specifies disease inspection, sampling and diagnostic procedures under sub. (3) (a), or additional disease certification requirements under sub. (2) (b) 3., constitutes an order under s. 93.07 (10), Stats., which is reviewable under ch. 227, Stats., and ch. ATCP 1 unless the department adopts those requirements by rule. If a health certification does not comply with instructions on the certification form, the certification is invalid.

(4) INTRODUCING DISEASED FISH.

No person may introduce live fish or fish eggs into waters of the state if that person knows, or has reason to know, that those fish or fish eggs are infected or show clinical signs of any reportable disease under s. ATCP 10.025.

appendix III. FISH TOLERANCE OF SELECTED AMPHIBIANS

Species Not at Risk

Terrestrial species with no exposure to fishes at any life stage.

- Allegheny Mountain Dusky Salamander, *Desmognathus ochrophaeus*
- Eastern Red-backed Salamander, *Plethodon cinereus*
- Northern Zigzag Salamander, *Plethodon dorsalis*
- Northern Ravine Salamander, *Plethodon electromorphus*
- Northern Slimy Salamander, *Plethodon glutinosus*

Fish-Tolerant Aquatic Species

Entirely aquatic species co-existing with fishes. They occupy aquatic microhabitats affording cover from predatory fishes, reduce predation by nocturnal activity, and guard their eggs.

- Hellbender, *Cryptobranchus alleghaniensis*
- Common Mudpuppy, *Necturus maculosus*

Fish-Tolerant Species

Species with behavioral and chemical adaptations to co-exist with fishes. These include distasteful secretions, very brief egg and larval periods, terrestrial adult stages, and preference for aquatic microhabitats affording cover from predatory fishes (weed beds and shorelines) and food resources not available to fishes (arthropods on floating vegetative mats and shorelines). Most achieve significantly higher population densities in the absence of fish, however, as they must compete with predatory and forage fishes for food. These species may colonize fish rearing ponds.

- Northern Cricket Frog, *Acris crepitans*
- American Toad, *Bufo americanus*
- American Bullfrog, *Rana catesbeiana*
- Green Frog, *Rana clamitans melanota*
- Pickerel Frog, *Rana palustris*
- Mink Frog, *Rana septentrionalis*
- Lesser Siren, *Siren intermedia*

Fish-Semi-Tolerant Species

Species that occasionally breed successfully in ponds with fish, either because the fish species are limited to non-predatory minnows and catfish, the density of fish is very low, or the wetland is complex and has at least some refugia from predatory fish. However, in the majority of cases, these species do not do well with fish.

- Smallmouth Salamander, *Ambystoma texanum*
- Tiger Salamander, *Ambystoma tigrinum*

- Northern Dusky Salamander, *Desmognathus fuscus*
- Northern Two-lined Salamander, *Eurycea bislineata*
- Southern Two-lined Salamander, *Eurycea cirrigera*
- Long-tailed Salamander, *Eurycea longicauda*
- Spring Salamander, *Gyrinophilus porphyriticus*
- Central Newt, *Notophthalmus viridescens louisianensis*
- Red Salamander, *Pseudotriton ruber*
- Great Plains Toad, *Bufo cognatus*
- Fowler's Toad, *Bufo fowleri*
- Canadian Toad, *Bufo hemiophrys*
- Crayfish Frog, *Rana areolata*
- Plains Leopard Frog, *Rana blairi*
- Northern Leopard Frog, *Rana pipiens*
- Southern Leopard Frog, *Rana utricularia*

Fish-Intolerant Species

These species have aquatic egg and/or larval stages that cannot tolerate fishes. Breeding is typically not attempted or unsuccessful where fishes are present.

- Jefferson Salamander, *Ambystoma jeffersonianum*
- Blue-spotted Salamander, *Ambystoma laterale*
- Spotted Salamander, *Ambystoma maculatum*
- Marbled Salamander, *Ambystoma opacum*
- Small-mouthed Salamander, *Ambystoma texanum*
- Four-toed Salamander, *Hemidactylium scutatum*
- Spadefoot, *Scaphiopus holbrookii*
- Cope's Gray Treefrog, *Hyla chrysoscelis*
- Gray Treefrog, *Hyla versicolor*
- Mountain Chorus Frog, *Pseudacris brachyphona*
- Spring Peeper, *Pseudacris crucifer*
- Strecker's Chorus Frog, *Pseudacris streckeri*
- Striped Chorus Frogs, *Pseudacris triseriata complex*
- Wood Frog, *Rana sylvatica*

appendix IV. SELECTED REFERENCES

The following list is a suggested source of more detailed information on topics discussed in this manual. Where cited, some of the information in this manual was borrowed from some of these sources.

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